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GANADERÍA

ESTIMACIÓN DE LAS NECESIDADES DE ENERGÍA Y PROTEÍNA EN POLLOS CRIOLLOS DE MÉXICO

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ESTIMACIÓN DE LAS NECESIDADES DE ENERGÍA Y PROTEÍNA EN POLLOS CRIOLLOS DE MÉXICO

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RESUMEN

Se realizaron dos investigaciones para estimar las necesidades de energía metabolizable (EM) y proteína cruda (PC) en pollos Criollos Mexicanos 1) del nacimiento a las 12 semanas de edad y 2) de 13 a 20 semanas de edad, evaluando el desempeño productivo, rendimiento en canal, medidas relativas de órganos digestivos, composición de todo el cuerpo y utilización de nutrientes. Cuatro dietas con diferentes concentraciones de EM (kcal/kg) /PC (%) fueron usadas: **3000/20**, **2850/19**, **2700/18** y **2550/17**. En la investigación 1) se utilizaron 236 pollos (59 aves por dieta) y en la 2) se utilizaron 192 pollos (48 aves por dieta), los cuales se distribuyeron aleatoriamente a una de las cuatro dietas experimentales. Los datos de ambos experimentos se analizaron con el procedimiento GLIMMIX de SAS con una estructura de covarianza AR (1), las medias ajustadas fueron comparadas con el método LSD a un nivel de significancia del 5%. En la investigación 1) las variables ganancia de peso (GP), mortalidad, rendimiento en canal, retención de grasa y retención de energía bruta (EB) y excreción de N no fueron diferentes por efecto de dietas. No obstante, los pollos de la dieta 3000/20, tuvieron los valores más bajos en consumo de alimento (CA), conversión alimenticia (CONV), peso del buche, peso de molleja, retención y eficiencia de retención de la PC que los pollos de la dieta 2550/17. En la investigación 2) los machos bajo la dieta 2550/17 tuvieron mayor CA y los machos en las dietas 2550/17, 2850/19 y 2700/18 obtuvieron mayor GP y peso corporal final. La CONV fue menor con la dieta 3000/20 y 2850/19. La retención de grasa del cuerpo completo fue mayor en hembras de la dieta 3000/20. En general, los machos presentaron mayor peso y rendimiento de canal y las hembras mostraron promedios mayores en órganos digestivos, retención de grasa y retención de EB. En conclusión: 1) es posible alimentar a los pollos Criollos de México del nacimiento a 12 semanas de edad con la dieta 2550/17, sin afectar GP, mortalidad, rendimiento en canal, y mejorando la retención y eficiencia de retención de PC y 2) los machos con la dieta 2550/17 obtuvieron mejor desempeño productivo, sin afectar rendimiento de la canal y la composición del cuerpo. Las hembras con la dieta 2700/18 mantuvieron el desempeño productivo, rendimiento de la canal y la composición del cuerpo.

Palabras clave: Pollos Criollos Mexicanos, energía metabolizable, proteína cruda, desempeño productivo, rendimiento de la canal, utilización de los nutrientes

ESTIMATION OF ENERGY AND PROTEIN NEEDS IN CREOLE CHICKENS FROM MEXICO

Miguel Ángel Matus Aragón, D.C.
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ABSTRACT

Two investigations were carried out to estimate the needs of metabolizable energy (ME) and crude protein (CP) in Mexican Creole chickens 1) from hatching to 12 weeks of age and 2) from 13 to 20 weeks of age, evaluating the productive performance, carcass yield, relative measures of digestive organs, whole body composition and nutrient utilization. Four diets with different concentrations of ME (kcal/kg)/ CP (%) were used: **3000/20**, **2850/19**, **2700/18** y **2550/17**. In investigation 1) 236 chickens were used (59 birds per diet) and in 2) 192 chickens were used (48 birds per diet), which were randomly distributed to one of the four experimental diets. The data from both experiments were analyzed with the GLIMMIX procedure of SAS with an AR (1) covariance structure, the adjusted means were compared with the LSD method at a significance level of 5%. In investigation 1) the variables body weight gain (BWG), mortality, carcass yield, fat retention and gross energy (GE) retention and N excretion were not different due to the effect of diets. Chickens on the 3000/20 diet had lower feed intake (FI), feed conversion ratio (FCR), crop weight, gizzard weight, retention and retention efficiency of CP than chickens on the 2550/17 diet. In investigation 2) males under diet 2550/17 had higher FI and males on diets 2550/17, 2850/19 and 2700/18 obtained higher BWG and final body weight. The FCR was lower with the diets having 3000/20 and 2850/19. Whole body fat retention was higher in females on diet 3000/20. In general, males had higher productive performance and carcass yield, and females showed higher digestive organs weight, fat and GE retention. In conclusion: 1) it is possible to feed the Mexican Creole chickens from hatching to 12 weeks of age with a diet having 2550/17, without affecting BWG, mortality, carcass yield, and improving retention and retention efficiency of CP and 2) males with diet 2550/17 showed better productive performance, without compromising carcass yield and body composition. Females with diet 2700/18 maintained productive performance, carcass yield and body composition.

Key word: Mexican Creole Chickens; Metabolizable Energy; Crude Protein; Productive Performance; Carcass Yield; Nutrient Utilization

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INTRODUCCIÓN GENERAL

De acuerdo con el SIAP (2020), la industria avícola mexicana representa la principal actividad pecuaria en el país, aportando el 63.2% de la producción, entre huevo (28.8%), carne de pollo (34.2%) y carne de pavo (0.2%). Asimismo, Camacho-Escobar et al. (2006), mencionaron que la avicultura de traspatio está presente en 85% de las unidades de producción, representando hasta un 10% de la producción avícola nacional (Lastra et al., 1998). La producción pecuaria es importante para las familias de zonas rurales, ya que les da la posibilidad de obtener proteína de buena calidad, lo que a su vez coadyuva la seguridad alimentaria y económica por la comercialización de los excedentes de los productos generados (López-González, 2012).

La producción pecuaria en el traspatio es un sistema caracterizado por la crianza de diferentes especies animales en un mismo espacio (Gutiérrez-Triay et al., 2007), siendo las aves Criollas (AC) uno de los principales recursos genéticos locales (Segura-Correa, et al., 2007), porque han estado bajo selección natural aproximadamente cinco siglos, desarrollando la capacidad de producir y reproducirse bajo condiciones deficientes de alimentación, ambientales y sanitarias (Padhi, 2016).

Las AC se alimentan principalmente de insectos, residuos de cultivos y de cocina (Bhuiyan et al., 2005). Sin embargo, se ha observado que mejorando su alimentación aumenta la ganancia de peso y en consecuencia aumenta la producción de carne y/o huevo (Addisu et al., 2013). Aunque hay antecedentes de la alimentación de las AC de México usando dietas con diferente concentración de energía metabolizable (EM) y proteína cruda (PC), se desconocen las necesidades nutricionales específicas de este genotipo de aves. Los antecedentes que se conocen acerca de estas aves son: Segura-Correa et al. (2004), utilizaron una dieta con 3,097.83 kcal de EM/kg y 21% de PC de 0 a 21 días de edad y una dieta con

2,997.52 kcal de EM/kg y 19% de PC, de 22 a 49 días de edad. Mata-Estrada et al. (2020), utilizaron dietas con 3,000 kcal de EM/kg y 19% de PC del nacimiento a 18 días y una dieta con 2,800 kcal de EM/kg y 18% de PC de 19 a 177 días de edad de los pollos Criollos de México. No obstante, son un recurso genético poco investigado y es necesario estimar los requerimientos nutricionales; entre ellos, los de EM y PC, para utilizar de manera eficiente su potencial genético para el objetivo de producción deseado (Nahashon et al., 2010).

OBJETIVOS E HIPÓTESIS

Objetivo General

Estimar las necesidades de energía metabolizable (EM) y proteína cruda (PC) en pollos Criollos Mexicanos del nacimiento a las 20 semanas de edad.

Objetivos Específicos

1. Evaluar el desempeño productivo, rendimiento en canal, medidas relativas de órganos digestivos, composición de todo el cuerpo y utilización de nutrientes en pollos Criollos Mexicanos del nacimiento a las 12 semanas de edad, alimentados con cuatro dietas con diferentes concentraciones de EM y PC.
2. Evaluar el desempeño productivo, rendimiento en canal, medidas relativas de órganos digestivos, composición de todo el cuerpo y utilización de nutrientes en pollos Criollos Mexicanos de 13 a 20 semanas de edad, alimentados con cuatro diferentes dietas con diferentes concentraciones de EM y PC.

Hipótesis General

Dietas con menores niveles de 3000 kcal de EM/kg y 20% de PC con una relación constante de 150 (kcal EM/% PC) mantienen o mejoran el desempeño productivo de los pollos Criollos de México del nacimiento a las 20 semanas de edad.

Hipótesis Específica

1. Dietas con menores niveles de 3000 kcal de EM/kg y 20% de PC con una relación constante de 150 (kcal EM/% PC) mantienen o mejoran el desempeño productivo de los pollos Criollos de México del nacimiento a las 12 semanas de edad.
2. Dietas con menores niveles de 3000 kcal de EM/kg y 20% de PC con una relación constante de 150 (kcal EM/% PC) mantienen o mejoran el desempeño productivo de los pollos Criollos de México de las 13 a las 20 semanas de edad.

REVISIÓN DE LITERATURA

La avicultura en México

En 2020, la avicultura en México generó aproximadamente el 63.2% del total de la producción pecuaria, lo que correspondió a 3.6 y 3.0 millones de toneladas de carne de pollo y huevo, respectivamente (SIAP, 2020). Con base en dichas cifras nuestro país ocupó el sexto lugar mundial en producción de pollo y el cuarto en la producción de huevo (UNA, 2020).

En México, se diferencian tres sistemas de producción avícola, intensivo, semi-intensivo y el traspatio; los cuales, se distinguen por su infraestructura, tecnología, estirpes de aves y objetivos de producción (Alonso-Pesado et al., 2009).

Las producciones intensivas se caracterizan tener las mejores tecnologías e infraestructura para el manejo de las aves; asimismo, manejan altas densidades y estirpes especializadas para la producción de carne o huevo, lo que genera la más alta producción con respecto a los otros dos sistemas de producciones avícolas (Ramírez et al., 2012).

Las producciones semi-intensivas se caracteriza por ser un sistema de producción avícola alternativo, que tiene como objetivo el cuidado y conservación de los recursos naturales, así como mejorar el bienestar animal. Por lo general, este tipo de sistema es desarrollado por productores de pequeña y mediana escala; en la cual, implementan aves camperas de crecimiento lento bajo sistemas de pastoreo (Andrade-Yucailla et al., 2016).

Las producciones de traspatio se localizan en zonas rurales y periurbanas, se lleva a cabo en los patios de los hogares y se caracteriza por criar un número reducido de aves como las AC, patos y guajolotes (Cuca-García et al., 2015). Los gastos económicos de producción son reducidos ya que las instalaciones son hechas de materiales de la región como maderas, piedras, palmas, cartones, entre otros. Asimismo, las aves son alimentadas con granos producidos en la región, desperdicios de comida y lo que las aves consuman en el pastoreo (Juárez-Caratachea y Ortiz-Alvarado, 2001; Camacho-Escobar et al., 2006; Itza-Ortiz et al., 2016).

Aves Criollas y el traspatio en México

El sistema de producción avícola de traspatio, solar, patio o huerta (Mariaca-Méndez, 2012; Flota-Bañuelos et al., 2016), es importante en las zonas rurales de países en vías de desarrollo como México, dado que el 85% de las familias de dicho sector de la población lo practica y obtiene de él productos ricos en proteína (carne y huevo) y dinero por la venta de los excedentes (Vieyra *et al.*, 2004).

Las aves en las que se basa este sistema de producción son en su mayoría Criollas, adaptadas a las distintas condiciones climáticas, alimenticias y sanitarias de la localidad (Henson, 1992; Albalat-Botana, 2011). Por lo general, el tamaño de la parvada es menor a 100 aves por unidad de producción y se encuentran mezclados con otros animales como cerdos, ovinos, bovinos y caninos (Alonso y Ulloa, 1996). La base de su alimentación es maíz, residuos de comida de la unidad familiar, insectos y plantas que logre consumir del predio. Alcanzan un peso corporal promedio de 2 kg a las 24 semanas de edad, y el inicio de la postura puede comenzar hasta las 30 semanas de edad. Se ha observado que su producción mensual puede oscilar entre 7 y 16 huevos (Juárez y Pérez, 2003).

No obstante su baja productividad, existe preocupación por conservar este recurso genético y a partir de la ley de desarrollo rural sustentable, que en sus objetivos marca contribuir a la soberanía y seguridad alimentaria de la nación mediante el impulso de la producción pecuaria del país, las AC son consideradas de importancia debido a que provee a las familias de zonas rurales proteína de calidad (con su carne y/o huevo) bajo condicione productivas deficientes

(Camacho-Escobar et al., 2016; Jerez-Salas, 2017). Sin embargo, el conocimiento de las AC es mínimo, y las investigaciones realizadas van enfocado a características morfométricas y fenotípicas (Juárez *et al.*, 2000; Lázaro *et al.*,2012; Camargo *et al.*, 2015; Vega-Murillo *et al.*, 2018), características del sistema de producción (Juárez-Caratachea et al., 2008; Chincoya *et al.*, 2016), evaluación de las variables productivas (Juárez-Caratachea y Ortiz-Alvarado, 2001; Segura-Correa *et al.*, 2007), calidad del huevo (Juárez-Caratachea *et al.*, 2010), entre otros. A pesar de estos estudios, se desconocen los requerimientos nutricionales de las AC, lo cual ayudaría a mejorar el desempeño productivo, obteniendo mayor producción de carne y huevo.

Concentraciones de EM y PC utilizadas en dietas para aves Criollas

Las AC se caracterizan por su crecimiento lento, alta conversión alimenticia y baja producción de carne y/o huevo (Jerez-Salas *et al* ., 1994 ; Segura, 1998) en comparación con aves de líneas comerciales. Tratar de mejorar los parámetros productivos requiere la aplicación de dietas balanceadas que cubran los requerimientos nutricionales. A pesar de la importancia de todos los nutrientes, las fuentes de EM y PC son los principales insumos integrados en las dietas de las aves (Perween et al., 2016). En el Cuadro 1 se presentan diversas investigaciones con AC y los niveles de EM y PC utilizadas en su alimentación.

Cuadro 1. Concentraciones de EM y PC en dietas de aves Criollas y razas locales

Referencia	Dietas	Resultados
Resnawati (1998)/ Indonesia	1) Se evaluaron cinco niveles de [1]EM:2300, 2450, 2600, 2750 y 2900 [2]kcal/kg con 14.71, 14.04, 14.80, 15.45, 14.95% de [3]PC respectivamente. 2) Se evaluaron seis niveles de lisina: 2.20, 2.40, 2.60, 2.80, 3.00 y 3.20 g/[4]Mcal	Evaluar los efectos de cinco niveles de EM y seis niveles de lisina en pollos nativos de Indonesia. 1) Los pollos tuvieron mayor ganancia de peso con la dieta con 2900 kcal/kg y 14% de PC. 2) Pollos alimentados con 3.30 g de lisina/Mcal de EM obtuvieron mayores ganancias de peso.
Juárez-Caratachea y Ortiz-Alvarado (2001)/ México	Las primeras 6 semanas de edad 3200 kcal EM/kg y 22%. PC. De la 7 a las 12 semanas de edad 2900 kcal EM/kg y 18% PC	Estudiar los indicadores de eficiencia alimentaria: consumo de alimento, ganancia de peso y conversión alimentaria. El consumo de alimento (48 g/día) y la ganancia de peso (645 g) a las ocho semanas de edad, indican que ésta es la etapa de mejor eficiencia alimentaria en los pollos criollos. Sin embargo, es hasta las 12 semanas de edad cuando estos pollos alcanzan el peso apto para consumo: 1 274 ± 146 g.
Kingori et al (2003)/ Kenia	Se evaluaron dietas con 10, 12, 14, 16 y 18% de PC	Investigar la respuesta de crecimiento de pollos autóctonos en crecimiento entre las 14 y 21 semanas de edad alimentados con diferentes concentraciones de PC. El requerimiento de PC para estos pollos entre las 14 y 21 semanas de edad es de 16%.
Prado-González et al. (2003)/ México	Nacimiento a las 4 semanas de edad 3000 kcal EM/kg y 21% PC. De la 5 a las 12 semanas de edad 2900 kcal EM/kg y 19% PC. De la 13 a la 16 semanas de edad 2850 kcal EM/kg y 16% PC	Estimar los parámetros genéticos para pesos corporales hasta las 16 semanas de edad de una población de pollos criollos. Las heredabilidades aditivas son bajas para el peso corporal de los pollos criollos durante la crianza.
Segura-Correa et al. (2004)/ México	Nacimiento a la 3 semana de edad 3093 kcal EM/kg y 21% PC, 4 a la 7 semana de edad 2997 kcal EM/kg y 19% PC	Evaluar el desempeño productivo de pollos Criollos, pollos Hubbard y sus cruzas; los cuatro grupos raciales evaluados fueron: 1) pollos Criollo; 2) pollos Criollo × Hubbard; 3) pollos 7/8 Hubbard × 1/8 Criollo; 4) pollos Hubbard. Los pollos Hubbard fueron los más pesados, seguido por las aves 7/8 Hubbard × 1/8 Criollo y Criollo × Hubbard; las aves con menor peso fueron los Criollos.

Referencia	Dietas	Resultados
Paredes-López et al. (2018)/ Perú	Las gallinas criollas se alimentaron a base maíz y de insumos que se podían encontrar en los campos. Las gallinas Hy-Line Brown fueron alimentadas con una dieta que contenía 2938 kcal EM/kg y 14.6% PC	Evaluar los perfiles bioquímicos de la sangre y la composición química de huevos de gallinas Criollas y Hy-Line Brown criadas en sistema extensivo e intensivo respectivamente. Se concluye que los niveles de perfiles bioquímicos y componentes químicos de los huevos son más altos en las gallinas criollas que en las gallinas Hy-Line Brown.
Tongsiri et al. (2019)/ Tailandia	Primeras 3 semanas de edad 2794 kcal EM/kg y 19% PC. Las siguientes 18 semanas 2842 kcal EM/kg y 15% PC.	Estimar los parámetros genéticos, la tasa de consanguinidad y el efecto de la consanguinidad sobre el crecimiento y los rasgos de producción de huevos de una raza de pollo nativa tailandesa bajo un manejo intensivo en un clima tropical. Se puede lograr mayor ganancia de peso seleccionando pollos de crecimiento más rápido. Se espera que al seleccionar pollos de crecimiento más rápido aumente el peso de los huevo.
Mata-Estrada et al. (2020)/ México	Nacimiento a los 18 días de edad 3000 kcal EM/kg y 19% PC, 19 a 177 días de edad 2800 kcal EM/kg y 18% PC	Evaluaron modelos de crecimiento de Gompertz-Laird, logístico, Richards y Von Bertalanffy para determinar cuál se ajusta mejor a los datos de los pollos criollos. El modelo Von Bertalanffy fue el que mejor explicó el crecimiento de las aves.
Nguyen Hoang et al. (2021)/ Vietnam	Primeras 4 semanas de edad 2950 kcal EM/kg y 19% PC. De la semana 5 a la 8 de edad 3000 kcal EM/kg y 17% PC. De la semana 9 a la 20 de edad 3050 kcal EM/kg y 15.5% PC	Determinar los modelos más apropiados para describir la curva de crecimiento del pollo Mia vietnamita. El modelo Gompertz es el más adecuado para describir la curva de crecimiento del pollo vietnamita.

[1]EM: energía metabolizable; [2]kcal: kilocalorías; [3]PC: proteína cruda; [4]MCAL: megacalorías

De acuerdo a las investigaciones mencionadas en el Cuadro 1, las concentraciones de EM utilizados dietas para aves criollas o razas locales variaron de 2300 a 3200 kcal/kg de alimento y la concentración de PC vario de 10 a 22%. Dichas concentraciones presentan una amplia variación, por lo que es importante establecer los requerimientos de EM y PC de las AC que puedan apoyar a desarrollar un mejor desempeño productivo.

Métodos para determinar las necesidades nutricionales en aves

Existen diferentes métodos para determinar los requerimientos nutricionales de las aves domésticas.

Método de comparaciones múltiples

Las comparaciones múltiples de las medias permiten examinar cuales medias son diferentes y estimar el grado de diferencia. Por lo general, con estos métodos se elige la concentración del nutriente más bajo a evaluar, que da una respuesta no estadísticamente diferente, a la respuesta obtenida con una mayor concentración del nutriente evaluado (Pesti et al., 2009). Perween et al. (2016), utilizaron estos métodos y evaluaron diferentes niveles de energía (2600, 2800 y 3000 kcal de EM/kg) y proteína (17, 19 y 21%) sobre el rendimiento productivo y el estado inmunológico en pollos Varanaja nativos de la India. Asimismo, Kamran et al. (2008), evaluaron dietas bajas en proteína manteniendo relaciones constantes entre energía y proteína sobre el rendimiento productivo y de la canal en pollos de engorda en las etapas de iniciación de 1 a 10 días de edad (23, 22, 21 y 20% de PC con 3036, 2904, 2772 y 2640 kcal de EM/kg, respectivamente), crecimiento de 11 a 26 días de edad (22, 21, 20 y 19% de PC con 3146, 3003, 2860 y 2717 kcal de EM/kg, respectivamente) y finalización de 27 a 35 días de edad (20, 19, 18 y 17% de PC con 3100, 2945, 2790 y 2635 kcal de EM/kg).

Polinomios ortogonales

Cuando los tratamientos en investigación son cuantitativos, es común que el investigador además de comparar los tratamientos esté interesado en conocer el grado del polinomio que mejor modela la naturaleza de la respuesta. Un polinomio ortogonal es una ecuación de regresión que asocia diferentes potencias de la variable independiente, las cuales son independientes una de otra (Herrera Haro y García-Artiga, 2010). Yoon et al. (2007), utilizaron este método y evaluaron el efecto y la concentración de selenio (0, 0.1, 0.2 y 0.3 ppm de Se) sobre el rendimiento productivo y la retención de selenio en pollos de engorda. Igualmente, Khalil et al. (2021), quienes evaluaron la EM aparente de cereales (trigo, sorgo, cebada y maíz) en pollos de engorda a diferentes edades.

Modelos de regresión no lineal

La regresión no lineal ha sido una herramienta útil para modelar las respuestas biológicas de las aves de corral (Alhotan et al., 2017), es utilizado para estimar las necesidades nutricionales de las aves (Faria et al., 2002 ; Mehri et al., 2010), con el supuesto que la alimentación con niveles crecientes de un nutriente en particular, da como resultado un cambio en la respuesta (aumento o disminución según el parámetro medido), hasta cierto punto (requerimiento mínimo o máximo) en el que la respuesta se estabiliza (Alhotan et al., 2017). Ejemplos de estos modelos podemos encontrar con Mehri et al. (2015), quienes estimaron las necesidades de lisina de la codorniz japonesa en la fase de crecimiento (durante la cuarta y quinta semana de edad) en la cual evaluaron seis dietas con diferentes niveles de lisina (0.84, 0.99, 1.14, 1.29, 1.44 y 1.59 %), los valores obtenidos en el desempeño productivo y rendimiento de la canal se ajustaron a los modelos no lineales para su determinación.

Método de libre elección

Es un método de alimentación alternativo en el que los ingredientes del alimento se proporcionan en comederos separados y las aves seleccionan por sí mismos alimentos energéticos, proteicos, minerales y vitamínicos según sea necesario. La alimentación de libre elección se basa en el principio de que las aves de corral pueden ajustar la ingesta en función de las necesidades de nutrientes (Fanatico et al., 2013).

Diversas investigaciones han generado ecuaciones para estimar las necesidades de los nutrimentos con base a sus constantes fisiológicas, peso, edad, sexo, temperatura ambiental, entre otros. En los siguientes apartados, se muestra ejemplos para predecir los requerimientos de EM y PC.

Predicción de los requerimientos de energía metabolizable en las aves

El principal objetivo de la formulación de dietas para pollos de engorda, es conseguir el mayor peso al mercado a la edad más temprana posible, mediante la aplicación de dietas balanceadas y altamente digestibles, que contenga todos los nutrimentos como proteínas, aminoácidos, vitaminas, carbohidratos, grasas, minerales y agua en cantidad, calidad y proporciones adecuadas (Cuca-García *et al*., 2016). A pesar de la importancia de todos los nutrimentos, las fuentes de energía y proteína son los de mayor concentración en la alimentación de las aves, por su costo y proporción de integración en las dietas. Sin embargo, para optimizar la eficiencia alimenticia en aves criollas para la producción de carne, se requiere conocer los requerimientos nutricionales a investigar.

La energía es requerida por los pollos, para el mantenimiento (tasa metabólica basal y actividades físicas vitales), el crecimiento de los tejidos corporales (ganancia de peso) y el mantenimiento normal de la temperatura corporal, la cual se genera a partir de los carbohidratos, grasas y proteínas de la dieta (Leeson y Summers, 2001). La energía dietética que excede la necesaria para el crecimiento normal y el metabolismo del ave, generalmente se almacena como grasa (Rabello *et al.*, 2006). La utilización óptima de nutrientes por el pollo se logra cuando la dieta contiene la proporción adecuada de energía con relación a los otros nutrientes necesarios para producir el crecimiento deseado, o composición corporal (Kamran *et al*., 2008). En general, los pollos tienen una capacidad notable para controlar su consumo de energía cuando se enfrentan a dietas o componentes de la dieta con una concentración variable de energía. Este importante mecanismo es la base de muchas decisiones tomadas durante la formulación de alimentos (Emmans, 1994).

El nivel de energía de la dieta parece ser un factor importante que determina el consumo de alimento. La cantidad consumida de alimento y/o de energía dependerá de las necesidades del animal que varían por su genética, tamaño, actividad, temperatura ambiental, ganancia de peso o simplemente para su mantenimiento. Por lo tanto, es de suma importancia que conozcamos los requisitos energéticos de los pollos durante cada etapa de su crecimiento y desarrollo y que tengamos información precisa sobre los valores de energía disponibles de los alimentos utilizados para formular sus dietas (Marsden y Morris, 1987; Leeson y Summers, 2001).

De acuerdo con Leeson y Summers. (2001), los requerimientos totales de energía metabolizable (EMt) son calculados de la siguiente manera: energía metabólica de mantenimiento (EMm) + energía metabólica para ganancia de peso (EMgp) + energía metabólica por temperatura ambiental (EMta).

Donde:

EMm = Tasa metabólica basal + Actividad

- Tasa metabólica basal= peso corporal promedio$^{0.75}$ (kg) x producción de calor basal (5.5 kcal kg^{-1} por hora) x 24 (horas del día).

- Actividad= Representa en promedio un 30% de la tasa metabólica basal.

EMgp = Energía metabolizable para retención de proteína (EMp)+ energía metabolizable para retención de grasa (EMg)

- EMp= retención de energía como proteína (kcal día^{-1}) /0.48 (eficiencia de la deposición de 1 g de proteína en el cuerpo)
- Retención de energía como proteína= ganancia de proteína corporal (peso corporal en ayuno x proporción de proteína en la canal 0.18) x valor calórico de la proteína en el cuerpo (5.5 kcal g^{-1})
- EMg= retención de energía como grasa (kcal día^{-1})/0.82 (eficiencia de la deposición de 1 g de grasa en el cuerpo)
- Retención de energía como grasa= ganancia de grasa corporal (peso corporal en ayuno x proporción de grasa en la canal 0.16) x valor calórico de grasa en el cuerpo (9.1 kcal g^{-1})
- De acuerdo con Emmans citado por Pesti *et al*. (1992), la ecuación para calcular los requerimientos de EMta (Kj día^{-1}) = peso corporal (kg) x (170 – 2.2 x (temperatura ambiente en °C)) + 5 (ganancia de peso (g))

Predicción de los requerimientos de proteína cruda en las aves

Las proteínas son de mucha importancia, ya que son parte estructural de los tejidos blandos del cuerpo, como músculos, tejido conjuntivo, colágeno, piel, plumas, uñas y la porción córnea del pico. Asimismo, la sangre cuenta con proteínas, como la albúmina y las globulinas, que ayudan a mantener la homeostasis, regulan la presión osmótica y actúan en cierto modo como un suministro de reserva de aminoácidos, entre otras funciones. Asimismo, el fibrinógeno, la tromboplastina y varias otras proteínas participan en la coagulación de la sangre. También se encuentra en la sangre las proteínas conjugadas, como la hemoglobina, que lleva el oxígeno a las células, y las lipoproteínas que se encuentran en las membranas celulares, donde comprenden glicoproteínas esenciales estructurales, enzimas y algunas hormonas (Leeson y Summers, 2001; Meyers *et al*., 2008).

Por ello, el contenido de proteína en la dieta tiene un impacto considerable en el crecimiento, conversión alimenticia y la composición corporal de los pollos de engorda (Smith *et al*., 1998; Bregendahl *et al*., 2002). Por lo tanto, la decisión de inclusión óptima de proteína en las dietas de pollos de engorda, depende de la calidad de la proteína (digestibilidad y contenido de aminoácidos esenciales), calidad deseada de la canal y de los costos económicos (Eits *et al*.,2005).

De acuerdo con Leeson y Summers (2001), en aves comerciales para determinar los requerimientos diarios de proteína cruda en pollos en desarrollo, se deben considerar las necesidades proteicas para ganancia de peso, así como mantenimiento y desarrollo de las plumas. De esta manera, los requerimientos diarios de proteína para ganancia de peso, pueden calcularse multiplicando la ganancia diaria en peso corporal (g) por 0.18 (18% de proteína en la canal) y dividiendo por 0.61 (61% de eficiencia de utilización de la proteína del alimento). Los requerimientos para el mantenimiento, se determinan con la pérdida diaria de nitrógeno endógeno (aproximadamente 250 mg de nitrógeno por kg de peso corporal) en pollos jóvenes, multiplicando el nitrógeno x 6.25 indica que casi 1600 mg de proteína se pierden por kg de peso corporal por día. De esta manera, el requerimiento de proteínas en la dieta para el mantenimiento, se obtiene multiplicando las perdidas endógenas de proteína (0.0016) por el peso corporal y dividido entre la eficiencia del 61% (0.61) en la utilización de proteínas.

A las tres semanas de edad, las plumas representan aproximadamente el 4% del peso corporal. Esto aumenta a aproximadamente el 7% a las 4 semanas de edad, y permanece relativamente constante a partir de entonces. El contenido de proteínas de las plumas es de alrededor del 82%. Por lo tanto, el requerimiento diario de proteínas para la producción de plumas, se puede determinar multiplicando el porcentaje del peso de las plumas (.04 a 0.07), por la ganancia diaria de peso corporal (g), el resultado es multiplicado por 0.82 (el porcentaje de proteínas en las plumas) y dividido por 0.61.

Requerimientos totales de Proteína =

$$Proteína\ para\ mantenimiento: \frac{0.0016\ x\ peso\ corporal}{0.61}$$

$$+\ Proteína\ para\ Ganancia\ de\ peso: \frac{Ganancia\ diaria\ de\ peso\ (g)\ x\ 0.18}{0.61}$$

$$+\ Proteína\ para\ la\ producción\ de\ Plumas: \frac{(0.04\ o\ 0.07) x\ ganancia\ de\ peso\ (g)\ \ x\ 0.82}{0.61}$$

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CHAPTER I. PRODUCTIVE PERFORMANCE OF MEXICAN CREOLE CHICKENS FROM HATCHING TO 12 WEEKS OF AGE FED DIETS WITH DIFFERENT CONCENTRATIONS OF METABOLIZABLE ENERGY AND CRUDE PROTEIN

1.1. ABSTRACT

Objective: The study aimed to evaluate the productive performance, carcass yield, size of digestive organs and nutrient utilization in Mexican Creole chickens, using four diets with different concentrations of metabolizable energy (ME, kcal/kg) and crude protein (CP, %).

Methods: Two hundred thirty-six chickens, coming from eight incubation batches, were randomly distributed to four experimental diets with the following ME/CP ratios: 3000/20, 2850/19, 2700/18 and 2550/17. Each diet was evaluated with 59 birds from hatching to 12 weeks of age. The variables feed intake (FI), body weight gain (BWG), feed conversion (FC), mortality, carcass yield, size of digestive organs, retention of nutrients, retention efficiency of gross energy (GE) and CP, and excretion of N were recorded. Data were analyzed as a randomized block design with repeated measures using the GLIMMIX procedure of SAS, with covariance AR (1) and adjustment of degrees of freedom (Kendward-Roger), the adjusted means were compared with the LSD method at a significance level of 5%.

Results: The productive performance variables BWG, mortality, carcass yield, fat and GE retention and excretion of N were not different ($p>0.05$) due to the diet effect. In the 3000/20 diet, the chickens had lower values of FI, FC, crop weight, gizzard weight, retention and retention efficiency of CP ($p<0.05$) than the chickens of the 2550/17 diet.

Conclusions: The Mexican Creole chickens from hatching to 12 weeks of age can be feed with a diet with 2550 kcal ME and 17% CP, without compromising productive parameters (BWG, mortality, carcass yield) but improving retention and retention efficiency of CP.

Keywords: Mexican Creole Chickens; Apparent Metabolizable Energy; Crude Protein; Productive Performance; Carcass Yield; Nutrient Utilization

1.2. INTRODUCTION

The production of Mexican Creole chickens provides animal protein and income to families in rural communities [1]. Birds of this genotype can survive and produce meat and eggs even with inadequate nutrition and unsanitary conditions [2]. Although Mexican Creole birds are an important genetic resource, they have been little studied and their nutritional requirements such as metabolizable energy (ME) and crude protein (CP) are unknown. Studying the retention efficiency of ME and CP is key in animal nutrition given that those nutrients represent approximately 90% of the total cost of the diet in domestic chickens [3]. Additionally, an imbalance in these components in the diet can retard growth [4] and reduce economic returns.

Feed intake (FI) in chickens is influenced by the concentration of ME in the diet. When diets are low in ME, FI increases. But if the feed is bulky and exceeds the storage capacity of the digestive system, the chickens may not consume adequate amounts of nutrients [4]. On the contrary, if the concentration of ME is high in relation to CP and amino acids, fat deposition can increase [5, 6] and body weight gain (BWG) can be compromised [4]. Excess CP in diet can results in excess of N excretion in litter house causing skin dermatitis, footpad lesions and hock burns and ammonia emission [7].

Although there are few studies on the feeding of the Mexican Creole chickens using diets with different concentrations of ME and CP, the specific nutritional needs of this genotype of birds are unknown. Some examples of these studies are: Segura-Correa et al [8], used a diet with 3,098 kcal ME/kg and 21% CP from 0 to 21 days of age and a diet with 2,998 kcal

ME/kg and 19% CP, from 22 to 49 days of age. Mata-Estrada et al [1], used diets with 3,000 kcal ME/kg and 19% CP from 0 to 18 days and a diet with 2,800 kcal ME/kg and 18% CP from 19 to 177 days of age. Therefore, the aim of this study was to evaluate the productive performance, carcass yield, size of digestive organs and nutrient utilization in Mexican Creole chickens, using four diets with different concentrations of metabolizable energy and crude protein, in order to have an estimation of the requirements of ME and CP in this genotype of birds.

1.3. MATERIALS AND METHODS

The experiment was carried out from January to July 2019, in the poultry facilities of the Colegio de Postgraduados, Campus Montecillo, in Texcoco, State of Mexico, Mexico, at coordinates 19 ° 29 ′ N, 98 ° 54 ′ W, and an altitude of 2,247 m.

1.3.1. Chickens and management

Two hundred thirty-six straight-run chicks, coming from eight incubation batches, were randomly distributed to four experimental diets. Each diet was evaluated with 59 birds (30 males and 29 females) from hatching to 12 weeks of age. At hatching, the chickens were individually identified with marks on the interdigital membranes, according to what was established by Storey [9]. From hatching to eight weeks of age, the birds were housed in electric brooders (0.040 × 0.110 × 0.040 m) with an initial temperature of 32 ° C, which was gradually reduced to 28 ° C. Later and until 12 weeks of age, the birds were housed in pens of 1.0 × 1.5 × 1.0 m, with a bed of wood shavings and an average room temperature of 24 ° C. Water and feed were provided *ad libitum* throughout the experimental period. The chickens were cared according to the guidelines established by the Animal Welfare Committee of the Colegio de Postgraduados, Campus Montecillo, State of Mexico, Mexico.

1.3.2. Experimental diets

Four diets were formulated with different concentrations of ME and CP (Table 1.1), maintaining constant ratios of 150 ME (kcal/kg) and CP (%): 3000/20; 2850/19; 2700/18 and 2550/17. The ingredients used in the formulation of the diets were analyzed with the NIRS^{TM} de foss model DS2500 equipment (Hilleroed, Denmark). Requirements of the essential amino acid, calcium and phosphorus were met according to the NRC [10] for broilers.

1.3.3. Productive performance

The productive performance variables: feed intake (FI; g/chicken), body weight gain (BWG; g/chicken), feed conversion (FC; g/g) were recorded weekly, and mortality daily.

1.3.4. Carcass yield

At 12 weeks of age, the weight of the carcass and its parts were determined, as well as the corresponding yields, according to Van Harn et al [7]. In each of the eight blocks (incubation batches), two birds were randomly selected per experimental diet, in total 16 birds per diet were obtained (eight males and eight females). Chickens were slaughtered according to the Official Mexican Standard NOM-033-SAG / ZOO-2014 [11], using a stunner electric knife followed by slaughtering and bleeding.

1.3.5. Digestive organs and abdominal fat

In addition to carcass yield variables data were also collected on relative empty weight of the crop, proventriculus, gizzard, small intestine and caeca, relative weight of liver, pancreas and abdominal fat, and relative length of the small intestine and caeca, according to Mera-Zuñiga et al [12]. These variables were expressed in relation to body weight.

1.3.6. Nutrient utilization

At 12 weeks of age, the chemical composition (moisture, dry matter [DM], CP, fat, ash and gross energy [GE]), nutrient retention (CP, fat and GE), GE and CP retention efficiency were determined for the whole-body of chickens, as well as excretion of N, according to the methodology described by Aletor et al [5]. Two birds were randomly selected per experimental diet in each block, in total 16 birds per diet (eight males and eight females).

The birds were subjected to a 12-hour of fast before they were slaughtered. The slaughter of the birds was performed using a stunner electric knife and cervical dislocation, while avoiding loss of blood. The whole-body of each chicken was frozen at -20 °C. Subsequently, these were thawed and placed in an autoclave for 5 hours at 110 °C and a pressure of 1 atm. Finally, each chicken body was individually placed in an industrial blender for 10 minutes and a sample of 300 g of ground meat was lyophilized and analyzed for chemical composition in order to estimate the values of nutrient retention, and retention efficiency of GE and CP. Analyzes of the chemical composition of the body were performed in triplicate, according to the AOAC [13]. The GE or heat of combustion was determined using an isoperibolic calorimeter (No. 1266, Parr instruments, Moline, IL, USA). The procedures described above to determine the chemical composition of the whole-body of the birds were also performed for a sample of 16 chickens at hatching.

Nutrient retention was estimated according to the following expression:

$$\text{CP retained (g)} = \text{ CP in the whole body of the chicken at 12 weeks of age} - \text{average CP in the whole body of chicks at hatching}$$

Likewise, fat and GE retained were calculated, substituting in the previous expression, the CP value for the fat (g) or GE (kcal) value, respectively.

The retention efficiency of GE and CP were calculated as follows:

$$\text{GE retention efficiency (\%)} = \frac{\text{kcal GE retained}}{\text{kcal GE consumed}} \times 100$$

$$\text{CP retention efficiency (\%)} = \frac{\text{g CP retained}}{\text{g CP consumed}} \times 100$$

Nitrogen excretion was calculated as follows:

$$\text{N excretion (g)} = \text{N consumed} -$$

$$\text{N retained in the whole body of the chicken at 12 weeks of age}$$

1.3.7. Statistical analysis

Data were analyzed according to a randomized block design with repeated measures using the GLIMMIX procedure of SAS version 9.4 (SAS Institute, 2013) [14], AR (1) covariance structure and Kenward-Roger degrees of freedom adjustment [15]. Statistical differences were established at $p<0.05$ and adjusted means were compared with the least significant difference (LSD) method. For the variables of productive performance and nutrient retention efficiency, the effect of diets was studied; while in the variables of carcass yield, size of digestive organs, chemical composition of the whole-body and nutrient retention, the effects of diet and sex of the chickens, as well as their interaction, were studied.

1.4. RESULTS

1.4.1. Productive performance

In the period from hatching to 12 weeks of age, differences ($p<0.05$) were detected among diets for the FI and FC variables. In contrast, BWG and mortality were not different ($p>0.05$) among the diets (Table 1.2). Feed intake was highest ($p<0.05$) in the 2550/17 and 2700/18 diets, followed by the 2850/19 and 3000/20 treatments. Feed conversion was lower ($p<0.05$) in the 3000/20 diet compared to the 2700/18 and 2550/17 diets.

1.4.2. Carcass yield

The diet had a significant effect ($p<0.05$) only on the weight of the wings (Table 1.3). The sex of the birds also affected ($p<0.05$) the variables studied, except for legs and thigh yield.

However, there was no diet × sex interaction ($p>0.05$) for any of the variables evaluated. The weight of the wings was significantly higher ($p<0.05$) in chickens fed the diet 2550/17 compared to the diet 3000/20. Male chickens had higher ($p<0.05$) weight and performance in most of the variables studied, except in breast and wing yields, which were higher ($p<0.05$) in females.

1.4.3. Digestive organs and abdominal fat

Diets affected ($p<0.05$) the relative weight of the crop, gizzard and pancreas (Table 1.4). Sex had an effect ($p<0.05$) on the relative empty weight of the proventriculus, gizzard and caeca, relative weight of liver and pancreas, and relative length of the small intestine and caeca. The relative weight of the crop was higher ($p<0.05$) in chickens fed diets 2850/19 and 2550/17 compared to those fed diet 3000/20. The relative weight of the gizzard was higher ($p<0.05$) in the chickens fed diet 2550/17 compared to the other diets. The relative weight of the pancreas was higher ($p<0.05$) in chickens fed diet 2550/17 compared to chickens fed diet 2850/19. Female chickens had a greater ($p<0.05$) weight of the proventriculus, gizzard, caeca, liver and pancreas, as well as a greater length of the small intestine and caeca, compared to male chickens.

1.4.4. Nutrient utilization

Chemical composition of the whole-body of the chickens was not affected ($p>0.05$) by diet, sex or the interaction (Table 1.5). Diet had a significant effect ($p<0.05$) on CP retention, and sex affected ($p<0.05$) CP and fat retention (Table 1.6). Chickens fed 3000/20 diet had lower ($p<0.05$) CP retention compared to the other three diets, and male chickens had higher ($p<0.05$) CP and fat retention than female chickens.

A lower ($p<0.05$) CP retention efficiency was observed in chickens fed diet 3000/20 compared to the other diets (Table 1.7). In contrast, the GE retention efficiency was lower

($p<0.05$) in the chickens fed the two diets with lower levels of ME and CP (2700/18 and 2550/17). Nitrogen excretion tended to be lower ($p<0.0961$) in chickens fed diet 2550/17 compared to those on the diet 3000/20, but differences were not statistically significant.

1.5. DISCUSSION

The Mexican Creole chickens are an unexplored genetic resource, so most of the variables evaluated in this study were compared with the results of investigations carried out in Creole and commercial chickens.

The present investigation showed that body weight gain of Mexican Creole chickens from hatching to 12 weeks of age was not affected by decreasing of ME and CP in the diet from 3,000 kcal ME/kg and 20% CP to 2,550 kcal ME/kg and 17% CP, keeping the levels of essential amino acids constant. However, feed intake and feed conversion increased. These results are consistent with other investigations [5, 16], where it was found that broilers fed with diets low in ME and CP can maintain body weight gain because feed intake increased. Likewise, Leeson and Summers [4] reported that by reducing ME in commercial poultry diets, feed intake increased to meet the chicken energy needs, which would explain the differences in feed conversion observed in this work.

Carcass yield was not affected by the experimental diets. In general, males showed higher weights and carcass yields than females. Probably these results are due to the constant levels of essential amino acids in the diets, particularly lysine and methionine, because these two amino acids are mainly involved in the formation of muscle tissue [17, 18].

The diets with a lower concentration of ME and CP allowed include more fibrous ingredients. There are some investigations that showed that moderate fiber inclusion in diets improves the development and functions of the gizzard [19, 20], increases the secretion of HCl, bile acids and enzymatic secretions from the pancreas [21]. This in turn improves the gastroduodenal reflux that facilitates the contact between nutrients and digestive enzymatic secretions. The improved contact increases the relative weight of crop, proventriculus and gizzard [22]. All the above mentioned may explain why chickens, fed with the diet lower in ME and CP, showed greater relative weight of the crop, gizzard and pancreas. Mabelebele et al [23] reported that digestive organs in male chickens are heavier and longer than in females, which can result in greater production of digestive enzymes and a greater contact surface for the absorption of nutrients, and result in a higher rate of growth. In the present experiment, the females had greater relative empty weight of the proventriculus, gizzard and caeca, greater relative weight of the liver and pancreas as well as greater relative length of the small intestine and caeca. This could be due to a lower value of the denominator when the relative weight was estimated [12, 24].

The chemical composition of the whole-body of chickens did not change by effect of the diet. This was probably due to the fact that a ratio of 150 (kcal ME kg/% CP) was kept constant in the experimental diets. It has been observed that increasing this ratio (>172) induces a higher rate of lipogenesis, which changes the chemical composition of the chicken body [5]. With the diet 3000/20, less CP retention was observed. This is consistent with Belloir et al [25], who reported lower retention of N in the body of male Ross PM3 chickens, when they were fed with diets with high CP content. In the present study, probably the energy of the diet was higher than that required by the birds, which resulted in a lower feed intake. In agreement with Leeson and Summers [4], birds fed the 3000/20 diet consumed fewer grams of CP compared to the others.

Females had lower retention of CP and fat, due to the fact that they had a lower live weight compared to males. That is, the content of CP and body fat varied due to the differences in body weight that result from the sexual dimorphism of chickens [26]. Some research reported that females had lower rates of CP deposition and higher fat deposition [27].

Chickens fed diets 2700/18 and 2550/17 had lower GE retention efficiency, which could be interpreted as a better balance of ME, CP, and amino acids, that decreased the availability of nutrients for storage via the catabolism of amino acids to form glycogen [25]. The CP retention efficiency was lower in chickens fed diet 3000/20, which agrees with Belloir et al [25], who observed lower N retention with diets high in CP due to deamination of amino acids, lower CP retention efficiency, and increasing N excretion [4].

1.6. CONCLUSION

In conclusion, it is possible to feed the Mexican Creole chickens from hatching to 12 weeks of age with a diet of 2,550 kcal ME/kg and 17% CP, without affecting body weight gain, and carcass yield, but improving the retention and retention efficiency of CP. These ME and CP values can be used as a reference point for the design of diets for this genotype of birds.

1.7. CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

1.8. ACKNOWLEDGMENTS

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Table 1.1. Composition (%) and calculated analysis of the experimental diets used

	ME[1] / CP[2] concentrations of diets			
Ingredients (%)	3000/20	2850/19	2700/18	2550/17
Maize	55.682	56.743	52.119	49.513
Soybean meal	24.037	19.827	14.899	14.154
Yellow corn DDGS[3]	6.000	6.000	6.000	5.701
Canola meal	6.000	6.000	6.000	5.701
Soybean oil	2.944	1.001	0.502	0.476
Wheat bran	2.000	6.894	16.736	15.898
Calcium carbonate	1.317	1.328	1.332	1.264
Dicalcium phosphate	0.910	0.913	0.907	0.861
Mineral-vitamin premix[4]	0.502	0.502	0.502	0.476
Sodium chloride	0.307	0.263	0.211	0.200
DL-Methionine	0.117	0.139	0.165	0.157
L-Lysine	0.069	0.173	0.288	0.274
Sodium bicarbonate	0.063	0.122	0.192	0.184
L-Threonine	0.052	0.095	0.147	0.141
Oat straw[5]	0.000	0.000	0.000	5.000
Calculated analysis (%)				
Metabolizable energy (kcal/kg)	3000.00	2850.00	2700.00	2550.00
Crude protein	20.00	19.00	18.00	17.00
Energy: protein ratio	150.00	150.00	150.00	150.00
Dry matter	88.80	88.60	88.60	88.80
Crude fiber	3.20	3.70	4.50	6.20
Calcium	1.00	1.00	1.00	1.10
Available phosphorus	0.45	0.45	0.45	0.44
Lysine	1.08	1.05	1.05	1.05
Methionine	0.47	0.40	0.40	0.41
Methionine+ Cystine	0.80	0.82	0.80	0.80
Threonine	0.75	0.78	0.75	0.75
Tryptophan	0.28	0.28	0.28	0.19

[1]ME= metabolizable energy; [2]CP = crude protein; [3]DDGS= dried distillery grains with solubles; [4]Provided the following per kilogram of diet: vitamin A, 12,000 UI; vitamin D3, 1,000 UI; vitamin E, 60 UI; vitamin K, 5.0 mg; vitamin B_2, 8.0 mg; vitamin B_{12}, 0.030 mg; pantothenic acid, 15 mg; niacin, 50 mg; folic acid, 1.5 mg; choline, 300 mg; biotin, 0.150 mg; thiamine, 3.0 mg. Fe, 50.0 mg; Zn, 110 mg; Mn, 100 mg; Cu, 12.0 mg; Se, 0.3 mg; I, 1.0 mg. [5]Oat straw was used as an inert filler in diet.

Table 1.2. Cumulative productive performance of Mexican Creole chickens from hatching to 12 weeks of age fed diets with different concentrations of ME and CP

Variable	ME[1] / CP[2] concentrations of diets				SEM	p-value
	3000/20	2850/19	2700/18	2550/17		
Feed intake (g/chick)	3761.43^{c}	4114.92^{b}	4359.07^{a}	4450.11^{a}	71.14	<0.0001
Body weight gain (g/chick)	1096.54	1148.97	1133.09	1095.15	34.28	0.6006
Feed conversion (g/g)	3.50^{c}	3.72^{bc}	3.95^{ab}	4.14^{a}	0.10	0.0006
Mortality (%)	8.13	2.58	10.00	3.33	7.51	0.1524

^{abc} Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME= metabolizable energy; [2]CP= crude protein; SEM= Standard error of the means.

Table 1.3. Carcass yield of 12-week-old of Mexican Creole chickens fed diets with different concentrations of ME and CP

Variable	ME[1] / CP[2] concentrations of diets				SEM	Sex		SEM	p-value		
	3000/20	2850/19	2700/18	2550/17		Male	Female		Diet	Sex	Diet × Sex
Body weight (g)	1061.39	1151.83	1116.80	1158.46	38.19	1250.31^{a}	993.93^{b}	27.12	0.0710	<0.0001	0.5700
Carcass weight (g)	693.33	754.09	725.94	767.62	27.97	839.02^{a}	631.47^{b}	19.78	0.1370	<0.0001	0.7940
Carcass yield (%)	65.32	65.47	65.00	66.26	1.24	67.10^{a}	63.53^{b}	0.89	0.9250	0.0026	0.5000
Breast weight (g)	167.56	173.95	174.44	186.86	8.38	191.66^{a}	159.74^{b}	5.22	0.1240	0.0002	0.6830
Breast yield (%)	24.17	23.07	24.03	24.34	0.67	22.84^{b}	25.30^{a}	0.47	0.1010	0.0012	0.4570
Leg weight (g)	106.03	119.24	109.32	121.41	4.45	131.34^{a}	96.66^{b}	3.18	0.5710	<0.0001	0.6970
Leg yield (%)	15.29	15.81	15.06	15.82	0.29	15.65	15.31	0.20	0.3300	0.3180	0.9260
Thigh weight (g)	107.36	119.65	114.18	121.15	6.72	131.52^{a}	99.66^{b}	4.80	0.2040	0.0002	0.7370
Thigh yield (%)	15.48	15.87	15.73	15.78	1.04	15.68	15.78	0.73	0.9170	0.5140	0.8140
Wings weight (g)	87.14^{b}	97.03^{ab}	91.00^{ab}	98.02^{a}	2.95	104.05^{a}	82.55^{b}	2.07	0.0380	<0.0001	0.8470
Wings yield (%)	12.57	12.87	12.54	12.77	0.24	12.40^{b}	13.07^{a}	0.17	0.9180	0.0260	0.5540

^{abc} Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME= metabolizable energy; [2]CP= crude protein; SEM= Standard error of the means.

Table 1.4. Organs size of 12-week-old of Mexican Creole chickens fed diets with different concentrations of ME and CP

Variable	ME[1] / CP[2] concentrations of diets				SEM	Sex		SEM	p-value		
	3000/20	2850/19	2700/18	2550/17		Male	Female		Diet	Sex	Diet × Sex
Relative empty weight (g/kg body weight)											
Crop	4.53^{c}	6.03^{a}	4.87^{bc}	5.47^{ab}	0.41	5.22	5.24	0.28	0.0480	0.6390	0.3020
Proventriculus	4.67	4.81	4.50	4.69	0.25	4.39^{b}	4.93^{a}	0.18	0.3540	0.0090	0.2750
Gizzard	22.32^{b}	21.94^{b}	22.71^{b}	26.13^{a}	1.01	20.74^{b}	25.72^{a}	0.71	0.0002	<0.0001	0.8310
Small intestine	18.03	18.94	18.60	18.70	1.34	17.59	19.50	0.93	0.6500	0.7400	0.5120
Caeca	4.28	4.00	4.07	4.09	0.24	3.87^{b}	4.34^{a}	0.17	0.7520	0.0410	0.5570
Relative weight (g/kg body weight)											
Liver	23.49	24.04	22.82	23.12	1.10	22.46^{b}	24.25^{a}	0.77	0.8950	0.0100	0.3420
Pancreas	2.53^{ab}	2.24^{b}	2.42^{ab}	2.94^{a}	0.21	2.35^{b}	2.72^{a}	0.15	0.0100	0.0150	0.9520
Abdominal fat	1.96	1.47	1.80	1.33	0.70	1.74	1.54	0.49	0.9120	0.8120	0.9500
Relative length (cm/kg body weight)											
Small intestine	102.43	104.02	105.19	100.70	5.31	93.76^{b}	111.89^{a}	3.75	0.6320	<0.0001	0.5500
Caeca	11.49	11.92	11.75	11.93	0.53	10.59^{b}	12.91^{a}	0.37	0.2970	<0.0001	0.2360

[abc] Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME= metabolizable energy; [2]CP= crude protein; SEM= Standard error of the means.

Table 1.5. Whole-body chemical composition of 12-week-old of Mexican Creole chickens fed diets with different concentrations of ME and CP

Variable	ME[1] / CP[2] concentrations of diets				SEM	Sex		SEM	p-value		
	3000/20	2850/19	2700/18	2550/17		Male	Female		Diet	Sex	Diet × Sex
Moisture (g/kg)	658.90	647.37	630.17	639.37	20.71	633.15	654.75	16.36	0.7087	0.2433	0.8303
DM[3] (g/kg)	341.10	352.63	369.83	360.63	20.71	366.85	345.25	16.36	0.7087	0.2433	0.8303
CP (g/kg)	220.78	232.56	249.95	246.69	12.75	243.88	231.12	9.97	0.2514	0.2700	0.4473
Fat (g/kg)	64.94	59.27	60.69	52.51	8.40	63.76	54.94	6.30	0.7084	0.2753	0.3627
Ash (g/kg)	29.73	28.20	31.06	31.00	3.86	31.84	28.15	2.98	0.9326	0.3000	0.2722
GE[4] (kcal/kg of DM)	4786.01	4972.10	4735.51	4564.85	117.75	4757.56	4771.67	82.38	0.151	0.907	0.3216

[1] ME= metabolizable energy; [2] CP= crude protein; [3] DM= dry matter; [4] GE= gross energy; SEM= Standard error of the means.

Table 1.6. Nutrient retention in the whole body of 12-week old of Mexican Creole chickens fed diets with different concentrations of ME and CP

	ME[1] / CP[2] concentrations of diets					Sex			p-value		
Variable	3000/20	2850/19	2700/18	2550/17	SEM	Male	Female	SEM	Diet	Sex	Diet × Sex
CP retention (g/chick)	191.57^{b}	267.23^{a}	288.37^{a}	256.97^{a}	14.83	289.76^{a}	212.32^{b}	9.94	0.0018	<0.0001	0.3220
Fat retention (g/chick)	56.98	68.45	66.33	53.51	8.31	73.66^{a}	48.97^{b}	5.69	0.5597	0.0096	0.2056
GE[3] retention (kcal/chick)	4716.73	4903.51	4666.11	4494.65	118.23	4688.88	4701.62	82.96	0.1493	0.9160	0.3013

^{abc} Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME= metabolizable energy; [2]CP= crude protein; [3]GE= gross energy; SEM= Standard error of the means.

Table 1.7. Retention efficiency of CP and GE in the whole-body of Mexican Creole chickens of 12 weeks of age fed diets with different concentrations of ME and CP

Variable	ME[1] / CP[2] concentrations of diets				SEM	p-value
	3000/20	2850/19	2700/18	2550/17		
CP retention efficiency (%)	25.46^{b}	34.18^{a}	36.75^{a}	33.97^{a}	2.48	0.0032
GE[3] retention efficiency (%)	29.77^{a}	29.75^{a}	26.58^{b}	25.22^{b}	0.74	0.0005
Nitrogen excretion (g/chick)	88.42	85.50	86.89	81.06	1.94	0.0961

^{abc} Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME= metabolizable energy; [2]CP= crude protein; [3]GE= gross energy; SEM= Standard error of the means.

CHAPTER II. PRODUCTIVE PERFORMANCE OF MEXICAN CREOLE PULLETS AND IMMATURE MALES FED DIFFERENT LEVELS OF METABOLISABLE ENERGY AND CRUDE PROTEIN

2.1. ABSTRACT

1. The aim was to evaluate the productive performance, carcase yield, relative measures of digestive organs, composition of the whole body and efficient utilization of nutrients in Mexican Creole pullets and immature males from 13 to 20 weeks of age, using four diets with different concentrations of metabolisable energy (ME, MJ/kg) and crude protein (CP, g/kg).

2. The experimental diets with constant ratios ME/CP equal to 0.06, were: 12.55/200, 11.92/190, 11.30/180 and 10.67/170. One hundred and ninety-two, 12- weeks-old, Creole birds (96 males and 96 females) were randomly distributed in the diets (24 males and 24 females each).

3. The variables considered were: feed intake (FI), body weight gain (BWG), feed conversion ratio (FCR), carcase yield, digestive organs weight, retention of CP, crude fat (CF) and gross energy (GE), and retention efficiencies of GE and CP.

4. Males on diet 10.67/170 consumed more feed and males on diets 10.67/170, 11.92/190 and 11.30/180 obtained higher BWG and final body weight. The FCR was lower on birds under the diets 12.55/200 and 11.92/190.

5. Whole body fat retention was higher in females on the diet 12.55/200. In general, males had higher productive performance and carcase yield, and females showed higher digestive organs weight, fat and GE retention.

6. In conclusion, males with diet 10.67/170 showed better productive performance, without compromising carcase yield and body composition while among females, birds with diet 11.30/180 showed the highest productive performance, carcase yield and body composition.

Keywords: Mexican Creole birds; Metabolisable Energy; Crude Protein; Feed Efficiency; Carcase yield; Abdominal Fat; Digestive Organ Size; Nutrient Utilization Efficiency

2.2. INTRODUCTION

Creole birds (*Gallus gallus domesticus*) of Mexico (CBMX) are birds with a lower growth rate compared to to breeds used (Mata-Estrada et al., 2020). Despite having a lower growth rate, they continue to be an important source of animal protein for families in rural areas (Kingori et al., 2003; Mata- Estrada et al., 2020). Thus, to increase the productivity additional informational is needed on the nutritional requirements of CBMX to efficiently use their genetic potential for the desired production objective (Nahashon et al., 2010).

The price of energy and protein sources for animal diets has been increased, which affects the cost of animal production (Baas-Osorio et al., 2019). Energy and protein represent approximately 90% of the total cost of poultry feed, so they must be used efficiently (Perween et al., 2016). Slow-growing breeds like CBMX do not appear to require a high concentration of metabolisable energy (ME) and crude protein (CP) for their growth and development (Gous, 2010). However, despite the National Research Council (NRC, 1994) recommends levels of ME and CP for broilers, there are no reports of requirements for slow-growing breeds, such as CBMX.

Matus-Aragón et al. (Forthcoming), showed that a diet with 10.67 MJ ME/kg and 170 g CP/kg offered from birth to 12 weeks of age, was sufficient to satisfy the ME and CP requirements of CBMX. However, the ME and CP requirements of CBMX from 13 to 20 week of age are unknown. The aim of this research was to evaluate the productive performance, carcase yield, relative measures of digestive organs, composition of the whole body and efficient utilisation of nutrient in Mexican Creole pullets and immature males from 13 to 20 weeks of age, fed with four different diets having different concentrations of ME and CP, but with a constant ratio of 0.06 between them (MJ ME kg^{-1}/g CP/kg).

2.3. MATERIALS AND METHODS

2.3.1. Period and place

The experiment was carried out from October to December 2019, in the experimental poultry unit of the Postgraduate College, Campus Montecillo, located in Texcoco, State of Mexico, Mexico, coordinates 19 ° 29 ′ N, 98 ° 54 ′ W, altitude of 2,247 m and average temperature of 16 °C.

2.3.2. Birds and handling

One hundred and ninety-two 12-weeks-old Mexican Creole immature birds (96 males and 96 females) were randomly assigned to four experimental diets. Each diet was evaluated with 48 birds (24 males and 24 females). Birds were housed individually in metal cages with dimensions of 60 × 60 × 60 cm, with a bed of wood shavings. A 16 h lighting with 8 h of darkness was provided and an average room temperature was maintained at 23 °C. Water and feed were provided ad libitum throughout the experimental period. Birds were handled following the regulations established by the Animal Welfare Committee of the Postgraduate

College, Montecillo Campus, State of Mexico, Mexico. The experiment was carried out with the methodology previously reported by Matus-Aragón et al. (Forthcoming).

2.3.3. Experimental diets

The ingredients used for diets formulation were analysed in triplicate with near infrared equipment (NIRSTM from foss model DS2500 Hilleroed, Denmark). Diets proposed and described by Matus-Aragón et al. (Forthcoming) were used. Four diets with different concentrations of ME and CP, maintaining constant ratios of 0.06 ME and CP (MJ ME kg^{-1}/g CP/kg): 12.55/200, 12.55 MJ ME kg^{-1} and 200 g CP/kg; 11.92/190, 11.92 MJ ME kg^{-1} and 190 g CP/kg; 11.30/180, 11.30 MJ ME kg^{-1} and 180 g CP/kg and 10.67/170, 10.67 MJ ME kg^{-1} and 170 g CP/kg. The diets were supplemented with essential amino acids, calcium and phosphorus in order to meet the NRC (1994) recommendations for broilers.

2.3.4. Productive performance

The productive performance variables were calculated each week: feed intake (FI; g/bird), body weight gain (BWG; g/bird) and feed conversion ratio (FCR; g/g).

2.3.5. Carcase yield

Live weight, carcase weight and yield were determined according to Van Harn et al. (2019). At 20 weeks of age, sixteen birds (eight females and eight males) per diet were randomly selected and slaughtered according to the Official Mexican Standard NOM-033-SAG / ZOO-2014 (2015). Birds were stunning with a stun knife (model VS-200, input power 120 V-1 A, output power 50 V- 0.1 A, Midwest Processing Systems, Minneapolis, MN, USA.) followed by slaughter and bleeding.

2.3.6. Digestive organs and abdominal fat

In the birds that were slaughtered the following variables were recorded: relative empty weight of the crop, proventriculous, gizzard, small intestine and cecum; relative weight of liver, pancreas and abdominal fat, and relative length of the small intestine and cecum, according to Mera-Zúñiga et al. (2019). These variables were expressed in relation to body weight.

2.3.7. Whole body composition

In addition, the following variables were determined: whole body composition (moisture, dry matter [DM], CP, fat, ash and gross energy [GE]); nutrient retention (CP, fat and GE); retention efficiency of GE and CP; and excretion of N, following the methodology described by Aletor et al. (2000) and Kamran et al. (2010).

2.3.8. Nutrient utilisation

For determining nutrient utilisation, sixteen birds of 12-week of age were randomly selected and slaughtered after 12 h of fasting. Immediately, they were desensitized with a stunning knife and cervically dislocated for avoiding blood loss. The whole body of the birds were frozen at -20 °C. Later, the bodies were thawed and placed in an autoclave for 5 hours at 110 °C and a pressure of 1 atm. Finally, each body was individually placed in a blender for 10 minutes and 400 g of this product were lyophilized for the composition analysis in order to estimate the nutrient retention values and the retention efficiency of GE and CP. All composition analyses were performed in triplicate, according to the AOAC (1990). The gross energy or heat of combustion was determined using an isoperibol calorimeter (No. 1266, Parr instruments, Moline, IL, USA). All the analyses described above were also performed in 16 birds of 12-weeks of age to determine the initial chemical composition of the whole body.

The nutrient retentions were calculated as follows:

Crude protein

$$\text{CP retention (g)}=\text{CP}_{\text{wbb\_20weeks\_age}}\text{-CP}_{\text{wbb\_12weeks\_age}}$$

Fat retention

$$\text{Fat retention (g)}=\text{Fat}_{\text{wbb\_20weeks\_age}}\text{-Fat}_{\text{wbb\_12weeks\_age}}$$

GE retention

$$\text{GE retention (kcal)}=\text{GE}_{\text{wbb\_20\_weeks\_age}}\text{-GE}_{\text{wbb\_12\_weeks\_age}}$$

were *wbb* stands for whole body of the bird.

The retention efficiency for GE and CP were calculated using the following formula

$$\text{GE retention efficiency (\%)}=\frac{\text{GE retention (kcal)}}{\text{GE consumption (kcal)}}*100$$

$$\text{CP retention efficiency (\%)}=\frac{\text{CP retention (g)}}{\text{CP consumption (g)}}*100$$

The nitrogen excretion was calculated as follows:

$$\text{N excretion (g)}=\text{N}_{\text{intake from 13 to 20 weeks}}\text{-N retention}$$

Where:

$$\text{N retention (g)}=\text{N}_{\text{wbb\_20weeks\_age}}\text{-N}_{\text{wbb\_12weeks\_age}}$$

2.3.9. Statistical analysis

All variables were analyzed using PROC GLIMMIX in SAS® (SAS version 9.4, SAS Institute, Cary, NC) using a repeated measures model with a 4 × 2 factorial arrangement (diet and sex), considering each bird as an experimental unit. The covariance structure that fitted better the data was an AR (1). The Kenward-Roger (1997) adjustment was used to correct the error degrees of freedom for the presence of multiple random effects in the model.

Pairwise comparisons of means were conducted using the LSD method at the 5% significance level.

2.4. RESULTS

2.4.1. Productive performance

Final body weight (FBW) and BWG were not different between diets (Table 2.1). The FI was statistically higher in the 10.67/170 diet, followed by the 11.30/180 diet, and those with the lowest FI were in the diets 11.92/190 and 12.55/200. FCR was significantly lower in the diets 12.55/200 and 11.92/190. Male presented higher FI, FBW and BWG.

The diet by sex interactions were significant on FI, FBW and BWG. As expected, male birds ate more feed than females. Male birds that received the diet 10.67/170 were those that consumed more feed, followed by the males under diets 11.30/180 and 11.92/190 (Figure 2.1A). In most diets, male birds were heavier than females. The FBW and BWG were significantly higher in the males under diets 10.67/170, 11.30/180 and 11.92/190 and significant differences were found between male and female birds in with the diets 12.55/200 and 10.67/170 (Figures 2.1B and 2.1C).

2.4.2. Carcase yield

The diet had a significant effect only on leg yield (Table 2.2). Differences were observed between sexes in all variables evaluated but the diet by sex interaction was not significant. Leg yield was higher in the 11.92/190 diet compared to 11.30/180 and 10.67/170, in contrast, with the diets 12.55/200 and 11.92/190 the leg yield was not different. In general, males presented higher weight and yield in most of the variables evaluated; except in breast, thigh and wing, which were higher yield in females.

2.4.3. Digestive organs and abdominal fat

Table 2.3 shows the relative measures for digestive system organs and abdominal fat. Weight and relative length of organs were influenced by the bird sex. Females showed greater empty weight of proventriculous, small intestine, caecum, liver weight and abdominal fat, relative length of small intestine and caecum. The diet-by-sex interaction was significant for the relative weight of abdominal fat. This variable was higher in females under diet 12.55/200, followed by the other experimental diets (Figure 2.2).

2.4.4. Whole body composition

Diet did not influence the whole body chemical composition of birds (Table 2.4); however, sex had a significant effect on moisture, DM, fat, ashes and GE, except CP. The interaction diet by sex was not significant. Females showed higher mean values in the DM, fat and GE variables while males showed only higher values in moisture and ash.

2.4.5. Nutrient utilisation

Nutrient retention and efficiency of nutrient retention were not influenced by diet while the variables fat retention, GE retention, GE retention efficiency, and N excretion were affected by bird sex. Only differences in fat retention were observed in the diet by sex interaction. Females presented higher values in fat retention, GE retention, GE retention efficiency and lower N excretion (Table 2.5). Similarly, females fed the 12.55/200 diet retained more fat than females on 10.67/170 and males in all experimental diets. Female birds under diets 11.92/190 and 11.30/180 did not show differences with the females in the diets 12.55/200 and 10.67/170. Similarly, there were no differences amongst male in all diets (Figure 2.3).

2.5. DISCUSSION

The CBMX are an important genetic resource whose nutritional requirements have been little studied, so the variables evaluated in this study were compared with the results of investigations carried out in Creole and commercial birds. Feeding Mexican Creole birds from 13 to 20 weeks of age with diets of 12.55/200, 11.92/190, 11.30/180 and 10.67/170, gave an estimate of the ME and CP requirements in these birds.

Our findings on the bird´s productive performance, agree with those previously reported by Matus-Aragón et al. (Forthcoming), where feeding birds from birth to 12 weeks of age with diets with lower ME and CP, increased feed intake (FI) and feed conversion ratio (FCR). Leeson and Summers (2001) and Classen (2017) indicate that FI in commercial birds is regulated by their energy needs, and FI increases when low ME diets are provided; which explains the differences in FI and FCR obtained in this study. Birds fed the 12.55/200 diet consumed less feed; however, the consumption of ME and CP was higher by 2.51%, 1.76% and 1.71% with respect to that consumed by the birds fed diets 11.92/190, 11.30/180 and 10.67/170. In the period from 13 to 20 weeks of age, the final body weight (FBW) and the body weight gain (BWG) were greater in the males with the diets 10.67/170, 11.30/180 and 11.92/190; on the contrary, females and males having the diet 12.55/200 gained lower weights and BWG with respect to the males with diet 10.67/170. These results can be related with findings by Lemme et al. (2004) who found that high CP content diets increases the proliferation of pathogenic microorganisms and the amount of undigested fractions in feces, which can produce poor intestinal health, increase environmental pollution and decrease the productive performance of birds (Apajalahti and Vienola, 2016). De Cesare et al. (2019)

found that feeding broilers diets reduced in CP, increased the concentration of lactobacilli in the caecum at 42 days of age, which may improve the retention efficiency of diets.

Regarding to carcase, the diet produced differences only in leg yield, while males presented higher weights and yields. This could be explained by the constant content of essential amino acids, for example, Si et al. (2001) and Vieira et al. (2004) found that using amino acids such as lysine and methionine in diets promoted the synthesis of muscle protein.

The relative measures of the digestive organs were statistically similar amongst treatments; in contrast, the abdominal fat was 62% and 50% higher in diet 12.55/200 compared to diets 11.30/180 and 10.67/170, respectively. Females had greater empty weight of the proventriculous, small intestine and caecum, weight of the liver and abdominal fat, as well as greater relative length of the small intestine and caecum. This could be due to the fact that the relative means were obtained according to Nitsan et al. (1991) as the ratio of the weight of the organ and the live weight of the bird (g/kg of body weight), as females had lower body weight than males, a higher relative weights were obtained in females.

Overall, the relative weight of abdominal fat in males was 15 times lower than in females. Baéza and Bihan-Duval (2013) mention that the body fat of commercial birds increases with a higher concentration of energy and CP in the diet. Furthermore, it has been observed that Creole birds reach sexual maturity about 22 weeks of age (Segura-Correa et al., 2007), and this physiological process is related to a higher lipogenesis for egg production (Pál et al., 2002; Wang et al., 2019).

The composition of the whole body of birds was not affected by the diets, probably due to the constant ratio of 0.06 between ME (MJ per kg) and CP (g/kg). Females showed higher

DM, fat and GE; in contrast, males had higher moisture and ash contents. Caldas et al. (2019) found a hydrophobic effect in Cobb broilers, as the content of CP and fat increases, the amount of water in whole body decreases. This could explain the results obtained in this study. Aletor et al. (2000) found a lower fat concentration (107.6 g/kg) in whole body of Lohmann male chickens (at six weeks of age), this value was three times greater than that of females in the current investigation. This result may indicate that the Mexican Creole birds have a lean carcase compared to commercial breed.

High fat retention values were observed in females fed with diets having high levels of ME and CP (12.55/200 diet). This high ME an CP concentration in the diet, induce a greater number of adipocytes in the abdominal region of females. This could be an evolutionary adaptation that increases fat storage capacity in females prior to reproduction (Langslow and Lewis, 1974). Similar results were found by Marx et al. (2016) and Filho et al. (2021) in commercial birds, who observed more abdominal fat in female than in males. This probably explains why females showed greater retention and retention efficiency of GE.

Although no differences were observed in protein retention, the excretion of N was higher in males, probably due to the higher FI. This increase in the excretion of N is influenced by the age of the birds (20 weeks of age), since the potential for protein deposition decreases with age (Samadi and Liebert, 2006). In turn, this produce an increase in amino acid deamination and nitrogen excretion.

2.6. CONCLUSION

In conclusion, it is possible to feed Mexican Creole male birds from 13 to 20 weeks of age with a diet containing 10.67 MJ ME/kg and 170 g CP/kg in order to maximize final body weight and weight gain, without affecting carcase yield and whole-body composition. In contrast, female birds can be fed a diet of 11.30 MJ ME/kg and 180 g CP/kg without affecting the variables of productive performance, carcase yield and whole-body composition. These ME and CP values can be used as a starting point for the design of diets for Creole birds of Mexico from 13 to 20 weeks of age.

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2.8. CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Table 2.1. Cumulative productive performance of Mexican Creole pullets and immature males from 13 to 20 weeks of age fed diets with different concentrations of ME and CP

Variable	Diet of ^{1}ME / ^{2}CP				SEM	Sex		SEM	p-value		
	12.55/ 200	11.92/ 190	11.30/ 180	10.67/ 170		Female	Male		Diet	Sex	Diet × Sex
Initial body weight (g/bird)	1172.8	1172.0	1193.7	1167.6	29.8	1167.0	1186.1	22.3	0.4972	0.5198	0.1211
Feed intake (g/bird)	5262.7^{c}	5400.9^{c}	5744.7^{b}	6085.7^{a}	155.1	5124.8^{b}	6122.1^{a}	149.7	<0.0001	<0.0001	<0.0001
Final body weight (g/bird)	1896.9	1925.5	1943.1	1924.8	29.8	1868.7^{b}	1976.5^{a}	24.1	0.4972	0.0001	0.0037
Body weight gain (g/bird)	724.1	753.5	749.4	757.2	24.3	701.7^{b}	790.4^{a}	22.8	0.6899	0.0067	0.0005
Feed conversion ratio (g/g)	7.31^{b}	7.38^{b}	8.07^{a}	8.21^{a}	0.26	7.56	7.92	0.25	0.0002	0.1973	0.6406

^{abc}Means with different superscripts within each row indicate differences ($p<0.05$). ^{1}ME = metabolizable energy (MJ/kg); ^{2}CP = crude protein (g/kg); SEM = standard error of the mean.

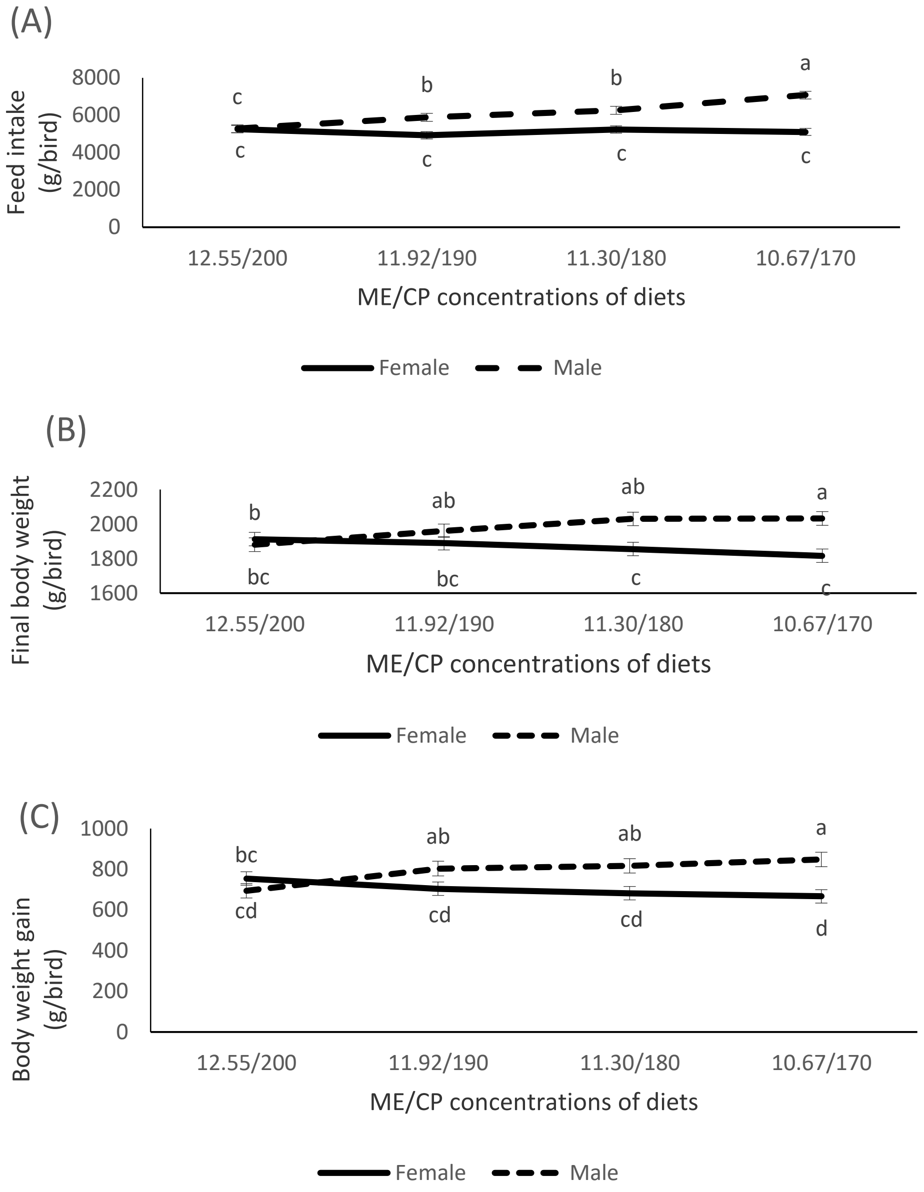

Figure 2.1. Diet × sex interaction of the cumulative productive performance of Mexican Creole pullets and immature males from 13 to 20 weeks of age: (A) feed intake, (B) final body weight and (C) body weight gain. ME = metabolisable energy (MJ/kg); CP = crude protein (g/kg). ^{abc}Means with different superscripts indicate differences ($p<0.05$).

Table 2.2. Carcase yield of 20-week-old Mexican Creole pullets and immature males fed diets with different concentrations of ME and CP

Variable	Diet of [1]ME / [2]CP				SEM	Sex		SEM	p-value		
	12.55/ 200	11.92/ 190	11.30/ 180	10.67/ 170		Female	Male		Diet	Sex	Diet × Sex
Carcase weight (g)	1136.37	12226.12	1232.56	1247.44	52.84	872.72^{b}	1548.53^{a}	37.36	0.4450	<0.0001	0.0988
Carcase yield (%)	62.66	64.43	65.15	65.05	1.48	56.90^{b}	71.74^{a}	1.05	0.6151	<0.0001	0.9346
Breast weight (g)	274.06	297.44	313.19	295.19	14.31	237.91^{b}	352.03^{a}	10.12	0.2980	<0.0001	0.2664
Breast yield (%)	24.71	25.40	26.27	24.27	0.71	27.64^{a}	22.68^{b}	0.50	0.2278	<0.0001	0.4511
Leg weight (g)	188.31	213.12	194.81	196.25	10.64	132.19^{b}	264.06^{a}	7.52	0.4057	<0.0001	0.2608
Leg yield (%)	16.45^{ab}	17.25^{a}	15.49^{bc}	15.35^{c}	0.37	15.29^{b}	16.98^{a}	0.26	0.0018	<0.0001	0.3587
Thigh weight (g)	194.44	203.87	206.00	214.69	10.05	155.47^{b}	254.03^{a}	7.11	0.5657	<0.0001	0.1541
Thigh yield (%)	17.34	17.00	16.89	17.33	0.45	17.87^{a}	16.41^{b}	0.32	0.8559	0.0024	0.7537
Wings weight (g)	137.37	147.37	143.69	158.44	5.88	118.06^{b}	175.37^{a}	4.16	0.0937	<0.0001	0.1828
Wings yield (%)	12.40	12.44	12.22	13.04	0.27	13.69^{a}	11.36^{b}	0.19	0.1570	<0.0001	0.2789

[abc]Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME= metabolizable energy (MJ/kg); [2]CP= crude protein (g/kg); SEM= standard error of the means.

Table 2.3. Relative measures (weight and length) of digestive organs and abdominal fat of Mexican Creole pullets and immature males of 20 weeks of age fed diets with different concentrations of ME and CP

Variable	Diet of ^{1}ME / ^{2}CP				SEM	Sex		SEM	p-value		
	12.55/200	11.92/190	11.30/180	10.67/170		Female	Male		Diet	Sex	Diet × Sex
Relative empty weight (g/kg body weight)											
Crop	4.19	3.41	3.45	3.57	0.43	3.63	3.68	0.30	0.5412	0.9018	0.3147
Proventriculous	3.39	3.89	3.45	3.46	0.20	3.85^{a}	3.25^{b}	0.14	0.3017	0.0050	0.4363
Gizzard	15.82	16.76	17.59	18.65	1.02	17.46	16.95	0.72	0.2588	0.6181	0.3042
Small intestine	15.57	16.84	17.00	14.73	0.78	18.51^{a}	13.56^{b}	0.55	0.1385	<0.0001	0.1143
Caecum	2.79	3.37	2.76	3.42	0.23	3.65^{a}	2.51^{b}	0.16	0.0787	<0.0001	0.3840
Relative weight (g/kg body weight)											
Liver	22.31	22.24	21.96	20.55	0.93	23.58^{a}	19.96^{b}	0.66	0.5095	0.0003	0.3560
Pancreas	1.96	1.86	1.90	2.08	0.14	2.02	1.88	0.10	0.7328	0.3460	0.7606
Abdominal fat	23.99^{a}	13.92^{ab}	9.22^{b}	11.87^{b}	3.18	27.71^{a}	1.79^{b}	2.25	0.0110	<0.0001	0.0097
Relative length (cm/kg body weight)											
Small intestine	76.81	75.34	75.31	72.06	2.00	83.04^{a}	66.72^{b}	1.42	0.4008	<0.0001	0.1807
Caecum	7.56	8.11	7.74	7.89	0.25	8.81^{a}	6.84^{b}	0.18	0.4782	<0.0001	0.0706

^{abc}Means with different superscripts within each row indicate differences ($p<0.05$). ^{1}ME = metabolizable energy (MJ/kg); ^{2}CP = crude protein (g/kg); SEM = standard error of the means.

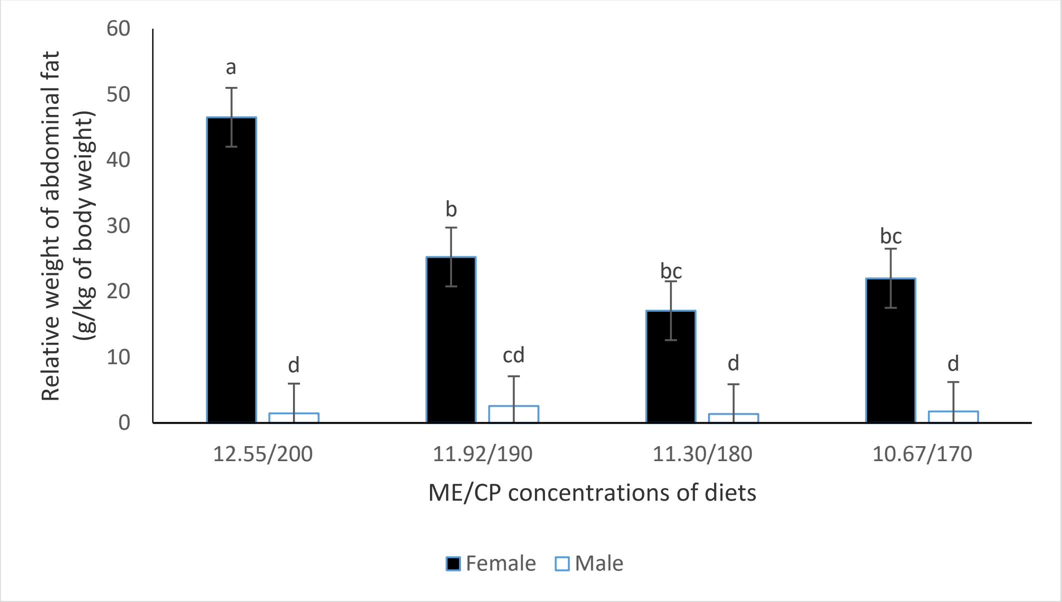

Figure 2.2. Diet × sex interaction for relative weight of abdominal fat (g/kg of body weight) in Mexican Creole pullets and immature males of 20 weeks of age. ME = metabolisable energy (MJ/kg); PC = crude protein (g/kg). ^{abc}Means with different superscripts indicate differences (p<0.05).

Table 2.4. Whole-body chemical composition of Mexican Creole pullets and immature males of 20 weeks of age fed diets with different concentrations of ME and CP

Variable	Diet of [1]ME / [2]CP				SEM	Sex		SEM	p-value		
	12.55/200	11.92/190	11.30/180	10.67/170		Female	Male		Diet	Sex	Diet × Sex
Moisture (g/kg)	668.21	639.22	649.59	660.96	13.97	618.62^{b}	690.38^{a}	9.87	0.4908	<0.0001	0.0794
[3]DM (g/kg)	331.79	360.78	350.41	339.04	13.97	381.38^{a}	309.62^{b}	9.87	0.4908	<0.0001	0.0794
CP (g/kg)	169.52	187.47	196.32	182.62	7.85	178.91	189.06	5.50	0.1404	0.2104	0.2390
Fat (g/kg)	26.60	24.50	20.80	21.30	2.60	34.90^{a}	11.70^{b}	1.80	0.3441	<0.0001	0.1019
Ash (g/kg)	100.52	100.46	103.22	101.82	5.73	85.04^{b}	117.97^{a}	4.05	0.9839	<0.0001	0.5188
[4]GE (MJ/kg of DM)	36.37	38.64	37.72	34.61	1.99	40.92^{a}	32.94^{b}	1.41	0.5335	0.0006	0.1226

[abc]Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME = metabolizable energy (MJ/kg); [2]CP = crude protein (g/kg); [3]DM = dry matter; [4]GE = gross energy; SEM = standard error of the mean.

Table 2.5. Whole-body nutrient retention and retention efficiency of 20-week-old Mexican Creole pullets and immature males fed diets with different concentrations of ME and CP

Variable	Diet of [1]ME / [2]CP				SEM	Sex		SEM	p-value		
	12.55/200	11.92/190	11.30/180	10.67/170		Female	Male		Diet	Sex	Diet × Sex
CP retention (g/bird)	61.32	69.12	71.33	56.90	12.59	67.03	62.31	8.90	0.8353	0.7115	0.1759
Fat retention (g/bird)	124.69	118.97	84.73	82.73	14.30	170.07^a	35.49^b	10.11	0.0970	<0.0001	0.0297
[3]GE retention (MJ/bird)	23.62	24.12	22.90	19.62	1.73	25.95^a	19.18^b	1.22	0.2793	0.0008	0.0681
CP retention efficiency (%)	5.31	6.24	6.65	6.00	1.31	6.72	5.38	0.92	0.9064	0.3182	0.1352
GE retention efficiency (%)	24.06	24.67	22.67	21.68	2.15	28.86^a	17.68^b	1.52	0.7593	<0.0001	0.1457
Nitrogen excretion (g/bird)	168.00	172.76	181.68	139.24	11.71	147.68^b	183.15^a	8.28	0.0914	0.0064	0.9011

[abc]Means with different superscripts within each row indicate differences ($p<0.05$). [1]ME = metabolizable energy (MJ/kg); [2]CP = crude protein (g/kg); [3]GE = gross energy; SEM = standard error of the mean.

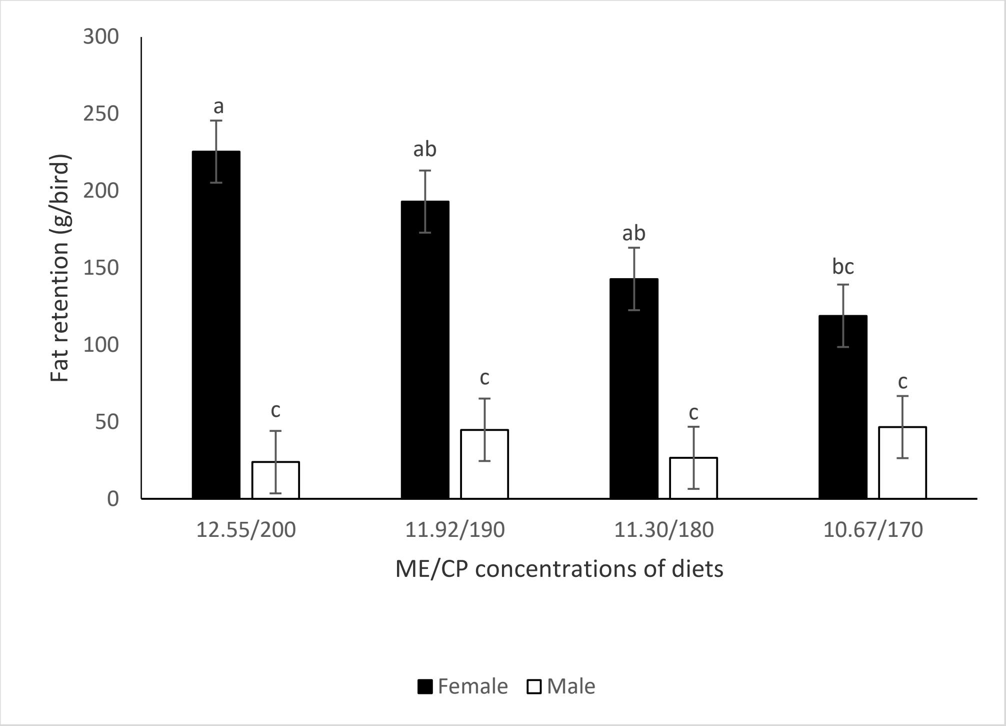

Figure 2.3. Diet × sex interaction in the whole body fat retention (g/chick) of 20-week-old of Mexican Creole pullets and immature males. ME = metabolizable energy (MJ/kg); CP = crude protein (g/kg). [abc]Means with different superscripts indicate differences ($p<0.05$).

CONCLUSIONES GENERALES

Las concentraciones de energía metabolizable y proteína cruda evaluados pueden emplearse como referencias para la elaboración de dietas de aves Criollas de México.

1) Del nacimiento a 12 semanas de edad es posible alimentar a las aves con 2550 kcal de EM/kg de dieta y 17% de PC.

2) De la 13 a las 20 semanas de edad, los machos Criollos obtuvieron mejor desempeño productivo con 2550 kcal de EM/kg de dieta y 17% de PC y en las hembras no se vieron afectada las variables productivas con 2700 kcal de EM/kg de dieta y 18% de PC.