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“Journal of Applied Animal Science” (JAAS)

Scope of the Journal

The philosophy of the Faculty of Veterinary Science, Mahidol University, is “One Health”, i.e., to interweave the disciplines of veterinary sciences with medical sciences for extreme advantages to human, animals and environment. The *Journal of Applied Animal Science (JAAS)*, is a peer review journal which published 2 numbers (January-June, July-December) a year by Faculty of Veterinary Science, Mahidol University, accepts manuscripts presenting information for publication with this philosophy in mind. Articles published in *JAAS* include a broad range of research topics in veterinary science, animal science, animal husbandry, animal production and fundamental aspects of genetics, nutrition, physiology, and preparation and utilization of animal products. Articles typically report research with cattle, companion animals, goats, horses, pigs, and sheep; however, studies involving other farm animals, aquatic and wildlife species, and laboratory animal species that address fundamental questions related to livestock and companion animal biology will be considered for publication.

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“Journal of Applied Animal Science” (JAAS)

สารจากฉบับนี้

เรียน ท่านผู้อ่านและผู้สนใจทุกท่าน

ในนามของคณะสัตวแพทยศาสตร์ มหาวิทยาลัยมหิดล ดิฉันขอแสดงความยินดีในการตีพิมพ์วารสาร **Journal of Applied Animal Science (JAAS) ปีที่ 18 ฉบับที่ 2** ซึ่งได้คัดสรรผลงานวิจัยที่เป็นภาพสะท้อนถึงวิวัฒนาการที่สำคัญของสัตวแพทยศาสตร์และสัตวศาสตร์ประยุกต์ในปัจจุบัน นั่นคือการบูรณาการนวัตกรรมขั้นสูงเพื่อความยั่งยืนในห่วงโซ่สุขภาพและอาหารสัตว์ โดยบทความในฉบับนี้แบ่งออกเป็นสองแกนหลักที่ขับเคลื่อนอนาคตของงานทางสัตวแพทยศาสตร์และสัตวศาสตร์ประยุกต์

1. การยกระดับสวัสดิภาพสัตว์ด้วยเทคโนโลยีการแพทย์ขั้นสูง

เราได้เห็นความก้าวหน้าอย่างก้าวกระโดดในการดูแลสุขภาพสัตว์ปีก ซึ่งเป็นความท้าทายทางกายวิภาคที่ซับซ้อน challenge ต่อขีดจำกัดเดิมของการรักษาตัวเล็ก บทความกรณีศึกษาเรื่อง การใช้ปากเทียมที่พิมพ์ด้วยเทคโนโลยี 3 มิติ (3D-printed upper beak prosthesis) ในนกแก้วขนาดเล็ก และการจัดการข้อต่อเคลื่อนหลุดด้วยอุปกรณ์ตรึงภายนอกแบบบานพับ (hinged transarticular external fixation) ในนกมาคอว์ได้แสดงให้เห็นถึงศักยภาพของการนำ digital fabrication และเทคนิคศัลยกรรมออร์โธปิดิกส์มาประยุกต์ใช้อย่างมีประสิทธิภาพ เพื่อฟื้นฟูสวัสดิภาพและคุณภาพชีวิตของสัตว์เลี้ยงได้อย่างสมบูรณ์

2. การเปลี่ยนของเสียให้เป็นแหล่งอาหารเพื่อความมั่นคงยั่งยืน

ในมิติของสัตวศาสตร์การผลิต บทความวิจัยได้นำเสนอ critique ต่อระบบอาหารแบบเส้นตรง (linear food system) ด้วยการมุ่งเน้นการจัดการทรัพยากรอย่างหมุนเวียน (circular economy) ผลงานวิจัยเรื่อง การประเมินคุณภาพผงไก่ออกจากไก่ที่เลี้ยงด้วยของเสียจากโรงฆ่าสัตว์ (abattoir wastes) และคุณค่าทางอาหารของกากเบียร์ผสมรำข้าวสาลี ได้ยืนยันถึงความคุ้มค่าและความยั่งยืนของการนำผลพลอยได้ทางการเกษตรและอุตสาหกรรมมาใช้เป็นแหล่งโปรตีนและพลังงานที่มีคุณภาพสำหรับสัตว์เลี้ยง เพื่อลดต้นทุนการผลิตและสร้างความมั่นคงทางอาหารอย่างยั่งยืน

งานวิจัยเหล่านี้ไม่ได้เป็นเพียงแค่การค้นพบใหม่ แต่เป็นการเชื้อเชิญให้เรา reconstruct กรอบความคิดในการพัฒนาสัตวศาสตร์ในภาพรวม เราต้องก้าวข้ามจากแค่การใช้เทคโนโลยีเพื่อการรักษา ไปสู่การวิจัยที่เน้นความทนทานทางชีวกลศาสตร์ในระยะยาวของวัสดุฝังเทียม และเปลี่ยนมุมมองจากการจัดการ "ของเสีย" ไปสู่การ "เก็บเกี่ยวทรัพยากรชีวภาพที่ถูกละเลย" (maximizing neglected bio-resources) เพื่อให้เกิดระบบการผลิตอาหารที่มีประสิทธิภาพสูงสุดต่อทั้งเศรษฐกิจและสิ่งแวดล้อม

ดิฉันขอชื่นชมทีมบรรณาธิการและนักวิจัยทุกท่าน ที่ได้ส่งมอบองค์ความรู้ที่มีคุณค่าและกำหนดทิศทางของสัตวแพทยศาสตร์และสัตวศาสตร์ประยุกต์ในทศวรรษหน้า หวังเป็นอย่างยิ่งว่า วารสารฉบับนี้จะเป็นแหล่งอ้างอิงและแรงบันดาลใจสำคัญให้กับชุมชนวิชาการต่อไป

รองศาสตราจารย์ ดร.สัตวแพทย์หญิงวลาสินี สักดีคำดวง

คณบดีคณะสัตวแพทยศาสตร์

มหาวิทยาลัยมหิดล

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คำแนะนำสำหรับผู้แต่ง

“Journal of Applied Animal Science” (JAAS)

วารสารสัตวศาสตร์ประยุกต์เป็นวารสารวิชาการราย 6 เดือน (2 ฉบับต่อปี เดือนมกราคม-มิถุนายน และเดือน กรกฎาคม-ธันวาคม) ของคณะสัตวแพทยศาสตร์ มหาวิทยาลัยมหิดล เผยแพร่ผลงานวิจัยครอบคลุมสหสาขาวิชาทั้งสัตวแพทยศาสตร์ และสัตวศาสตร์ ตั้งแต่พื้นฐานถึงระดับโมเลกุล รวมถึงรายงานทางคลินิก บทความที่ได้รับการตีพิมพ์ในวารสารต้องผ่านการประเมินโดยผู้ทรงคุณวุฒิอย่างน้อย 3 ท่าน ในรูปแบบ double-blind peer review

ผู้สนใจส่งบทความเพื่อตีพิมพ์ในวารสารสัตวศาสตร์ประยุกต์กรุณาปฏิบัติตามคำแนะนำและส่งพร้อมจดหมายนำ

1. ประเภทบทความ ที่รับพิจารณาได้แก่ รายงานการวิจัย รายงานฉบับย่อ บทความปริทัศน์และรายงานทางคลินิกเขียนด้วยภาษาไทยหรือภาษาอังกฤษ แต่บทคัดย่อต้องมีทั้งภาษาไทยและภาษาอังกฤษ

2. การส่ง ส่งต้นฉบับพร้อมสำเนา 4 ชุด และไฟล์ดิจิทัลทางไปรษณีย์ ไฟล์ดิจิทัลต้องสร้างด้วยโปรแกรม MS-Word หรือซอฟต์แวร์ที่ใช้แทนกันได้ อาจส่งต้นฉบับผ่านอีเมลโดยไม่มีสำเนาได้

3. รูปแบบ ขนาดกระดาษเอ 4 พิมพ์หน้าเดียว เว้นระยะ 1 บรรทัด ขอบกระดาษ 2.54 ซม. (1 นิ้ว) ฟอนต์ Angsana New หรือ TH SarabunPSK 16 พอยต์

4. ส่วนประกอบ รายงานการวิจัยต้องประกอบด้วยหน้าแรก (ได้แก่ ชื่อเรื่อง ชื่อผู้แต่ง สถานที่ทำงานและที่อยู่ ชื่อผู้แต่งหลักพร้อมที่อยู่ติดต่อได้และอีเมล พิมพ์ทั้งภาษาไทยและภาษาอังกฤษ) บทคัดย่อ (สั้นกระชับได้ใจความและคำสำคัญ 3-4 คำ) บทนำ อุปกรณ์และวิธีการ ผลการวิจัย วิจารณ์ กิตติกรรมประกาศและเอกสารอ้างอิง

ก. รายงานฉบับย่อและรายงานทางคลินิก อาจเขียนโดยไม่แยกหัวข้อ หรืออาจรวมส่วนผลการวิจัยและวิจารณ์เป็นหัวข้อเดียว

ข. บทความปริทัศน์ ควรเริ่มด้วยบทนำ แล้วบรรยายโดยแยกตามหัวข้อที่ต้องการนำเสนอ พร้อมบทสรุป

5. ตาราง-รูปภาพ ตารางและรูปภาพให้แทรกไว้ท้ายสุดของบทความ คำบรรยายตารางพิมพ์ด้านบน คำบรรยายรูปภาพพิมพ์ใต้ภาพ และมีหมายเลขอาระบิกกำกับตามลำดับการอ้างอิง ตารางควรเข้าใจได้ง่าย ให้ส่งรูปภาพความละเอียดสูงแยกต่างหากมาพร้อมด้วย

6. การอ้างอิง ผู้แต่งต้องปฏิบัติตามรูปแบบการอ้างอิงของวารสาร การอ้างอิงในเนื้อหาใช้ระบบนาม-ปี เช่น (คัมภีร์ กอธีระกุล และคณะ 2530) หรือ คัมภีร์ กอธีระกุล และคณะ (2530) การเขียนรายการเอกสารอ้างอิงให้เขียนไว้หลังกิตติกรรมประกาศ โดยพิมพ์เอกสารภาษาไทยก่อนแล้วตามด้วยเอกสารภาษาอังกฤษ สำหรับการเขียนเอกสารอ้างอิงภาษาอังกฤษให้ดูจากส่วนแนะนำภาษาอังกฤษ

คัมภีร์ กอธีระกุล, เทิด เทศประทีป, วรา พานิชเกรียงไกร, โสมทัต วงศ์สว่าง, วราภรณ์ แซ่ลี, สมศักดิ์ ภักษิธิภรณ์. การสำรวจพบเชื้อ *อี.โคไล* ซีโรไทป์ K88 จากลูกสุกรวัยคุดนมและหลังหย่านม. *เวชสารสัตวแพทย์*. 2530; 17(1): 21-7.

7. ชื่อวิทยาศาสตร์ ให้พิมพ์เป็นภาษาอังกฤษตามประมวลนามศัพท์สากลและทำให้เด่นแตกต่างจากเนื้อหา

8. การถอดคำไทยเป็นภาษาอังกฤษ ใช้หลักเกณฑ์การถอดอักษรไทยเป็นอักษรโรมันแบบถ่ายเสียงของราชบัณฑิตยสถาน

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- Fairbrother JM, Gyles CL. Escherichiacoliinfections. In: Straw BE, Zimmerman JJ, D'Allaire S, Taylor DJ, editors. Diseases of swine. 9th ed. Iowa: Blackwell Publishing; 2006. p. 639-74.
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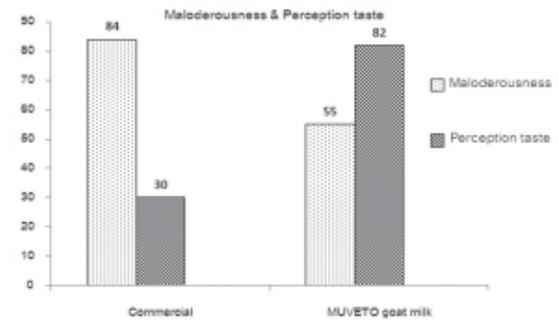
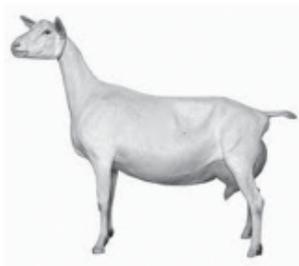
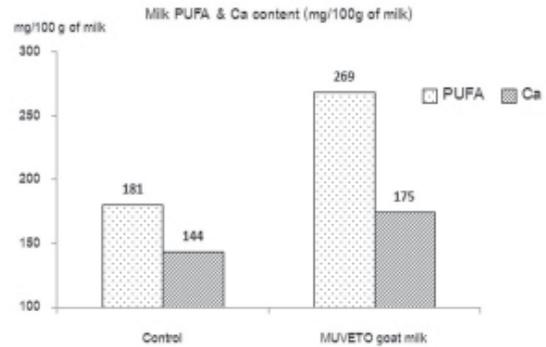
สวัสดีครับท่านผู้อ่านและสมาชิกวารสาร Journal of Applied Animal Science (JAAS) ทุกท่าน วารสารฉบับปิดท้ายประจำปี พ.ศ.2568 นี้ ได้นำเสนอผลงานวิชาการที่มีคุณค่าเชิงวิชาการและมีศักยภาพต่อการนำไปประยุกต์ใช้ทั้งในการรักษาสัตว์และการผลิตสัตว์อย่างยั่งยืน โดยรวบรวมองค์ความรู้จากนักวิจัยทั้งในประเทศและต่างประเทศ ซึ่งสะท้อนถึงความมุ่งมั่นของวารสารในการพัฒนาคุณภาพงานวิจัยและก้าวสู่มาตรฐานสากลอย่างต่อเนื่อง

ผลงานที่ตีพิมพ์ในฉบับนี้ประกอบด้วยรายงานสัตว์ป่วยจากประเทศไทย จำนวน 2 เรื่อง ได้แก่ การผ่าตัดตัดติ่งปากเทียมสามมิติบริเวณปากบนในนกฟอส (Forpus coelestis) และ การใช้การตรึงภายนอกแบบบานพับระหว่างข้อต่อเพื่อรักษาข้อเคลื่อนหลุดบริเวณข้อเข้าในนกแก้วบลูแอนด์โกลด์มาคอว์ นอกจากนี้ยังมีบทความวิจัยจากนักวิจัยต่างประเทศ จำนวน 2 เรื่อง ได้แก่ Nutritive Value and In-Vitro Digestibility of Blended Ratios of Wheat Offal and Wet Sorghum Brewer Residue as Feed for Livestock และ Quality Evaluation of Chicken Powder from Broiler Chicken Fed Abattoir Wastes in Their Diet

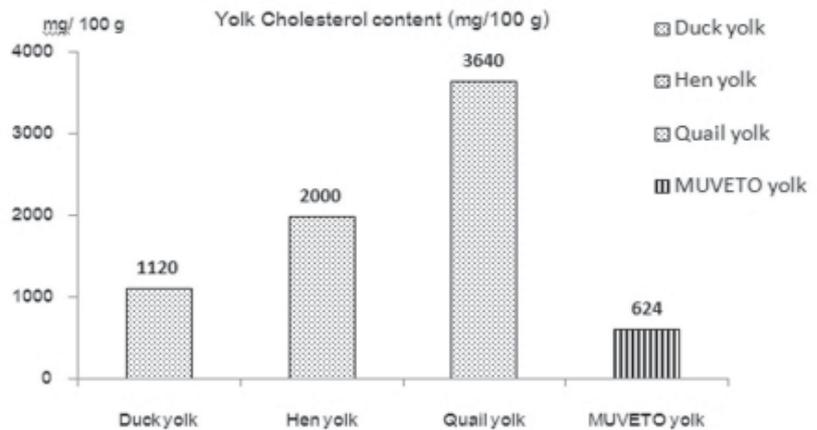
ทางกองบรรณาธิการขอเชิญชวนนักวิจัย คณาจารย์ และผู้เชี่ยวชาญทุกท่าน ส่งผลงานทางวิชาการที่มีคุณภาพและน่าสนใจมาร่วมเผยแพร่ โดยทุกบทความที่ตีพิมพ์จะผ่านกระบวนการพิจารณาอย่างเข้มงวดแบบ Double-Blind Peer Review จากผู้ทรงคุณวุฒิ เพื่อให้มั่นใจว่าผลงานจะสร้างคุณประโยชน์ต่อวงการสัตวแพทย์และสัตวศาสตร์ทั้งในและต่างประเทศ ในนามของกองบรรณาธิการขอกราบขอบพระคุณทุกท่านที่ให้การสนับสนุนมาโดยตลอด และหวังว่าจะยังได้รับความร่วมมือด้วยดีในปีต่อไป ขออวยพรให้ทุกท่านมีความสุขและประสบความสำเร็จในช่วงเทศกาลส่งท้ายปีเก่าต้อนรับปีใหม่

รองศาสตราจารย์ ดร.นายสัตวแพทย์ธนศักดิ์ ช่างบรรจง

บรรณาธิการ (Editor-in-Chief)



Functional goat milk: Naturally high PUFA, Ca and malodorousness



Functional egg: Low cholesterol



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Surgical Application of a 3D-Printed Upper Beak Prosthesis in a Pacific parrotlet (*Forpus coelestis*): A Preliminary Case Report

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Abstract

Severe beak deformities or loss in psittacine birds significantly impair essential functions such as feeding, preening, and climbing. This case report presents the first documented surgical implantation of a 3D-printed upper beak prosthesis in a Pacific parrotlet (*Forpus coelestis*), a small parrot species that presents unique anatomical and mechanical challenges. The patient, a female parrotlet, had suffered complete upper beak loss following a traumatic injury. A patient-specific prosthetic beak was digitally designed based on computed tomography imaging of conspecific anatomy, then fabricated using stereolithography 3D printing and coated with dental composite resin to enhance biocompatibility and durability. Surgical fixation was achieved using a titanium orthodontic miniscrew, transcranial stainless steel wire, and composite resin sealing, with the procedure completed within approximately 15 minutes to minimize anesthetic risk. Postoperatively, the bird began eating soft food independently by day 3 and resumed functional behaviors including food manipulation and perching. Long-term monitoring revealed stable prosthesis integration for one year. At that point, granulation tissue developed at the interface, leading to gradual loosening and the elective removal of the prosthesis. This case highlights the feasibility and clinical potential of using 3D-printed prosthetics for beak reconstruction in small avian species. The approach provides a reproducible framework that can be adapted to both smaller and larger parrots, offering a valuable treatment option for traumatic beak loss across a range of bird species. It also underscores the role of digital fabrication in advancing avian reconstructive surgery and improving animal welfare.

Keywords: Beak prosthesis, 3D-printed, Implantation, Parrotlet, Rhinotheca

การผ่าตัดติดตั้งปากเทียมสามมิติบริเวณปากบนในนกฟอส (Forpus coelestis): รายงานเบื้องต้นของกรณีศึกษา

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บทคัดย่อ

การเสีรูปร่างหรือการสูญเสียปากในนกแก้ว ส่งผลกระทบอย่างรุนแรงต่อพฤติกรรมพื้นฐานที่จำเป็นต่อการดำรงชีวิต เช่น การกินอาหาร การดูแลตนเอง และการสืบพันธุ์ รายงานฉบับนี้จึงนำเสนอกรณีศึกษาครั้งแรกของการผ่าตัดติดตั้งปากเทียมที่ผลิตด้วยเทคโนโลยีการพิมพ์สามมิติ (3D printing) บริเวณปากบนของนกแก้วสายพันธุ์แปซิฟิกพารอเล็ต หรือนกฟอส (Pacific parrotlet; *Forpus coelestis*) ซึ่งเป็นนกแก้วขนาดเล็กที่มีข้อจำกัดทางกายวิภาคและกลไกเฉพาะตัว สัตว์ป่วยรายนี้เป็นนกฟอสเพศเมียที่ได้รับบาดเจ็บจากอุบัติเหตุโดนนกที่มีขนาดใหญ่กว่ากัด ส่งผลให้สูญเสียปากส่วนบนทั้งหมด การรักษาประกอบด้วย การออกแบบปากเทียมเฉพาะรายโดยอิงจากภาพถ่ายเอกซเรย์คอมพิวเตอร์ (Computerized tomography scan) ของนกสายพันธุ์เดียวกัน จากนั้นผลิตชิ้นงานด้วยเทคโนโลยีการพิมพ์สามมิติด้วยเทคนิคสเตอริโอลิโธกราฟี และเคลือบด้วยเรซินทางทันตกรรม เพื่อความเข้ากันได้ทางชีวภาพและความทนทานในการใช้งาน ขั้นตอนการผ่าตัดเริ่มจากการฝังสกรูไทเทเนียมขนาดเล็กบริเวณปากส่วนบนที่เหลือ ร้อยลวดสแตนเลสผ่านกะโหลก และยึดปากเทียมเข้ากับกะโหลกร่วมกับรอยต่อด้วยเรซินทันตกรรม โดยทั้งหมดใช้เวลาเพียงประมาณ 15 นาที ซึ่งช่วยลดความเสี่ยงจากการวางยาสลบที่มักพบในนกขนาดเล็ก ภายหลังการผ่าตัด นกเริ่มกินอาหาร นมได้ด้วยตนเองภายใน 3 วัน และกลับมาแสดงพฤติกรรมการใช้ปากตามธรรมชาติได้อย่างต่อเนื่อง จากการติดตามผล พบว่าปากเทียมสามารถคงสภาพและทำงานได้อย่างมีประสิทธิภาพเป็นระยะเวลาหนึ่งปี ก่อนที่จะเริ่มหลุดออกเนื่องจากมีเนื้อเยื่ออกทดแทน (Granulation tissue) ก่อตัวบริเวณจุดยึด จึงมีการถอดอุปกรณ์ออกเพื่อป้องกันภาวะแทรกซ้อนในอนาคต รายงานฉบับนี้สะท้อนให้เห็นถึงศักยภาพและความเป็นไปได้ทางคลินิกในการประยุกต์ใช้เทคโนโลยีการพิมพ์สามมิติเพื่อการบูรณะปากในนกขนาดเล็กได้อย่างมีประสิทธิภาพ อีกทั้งยังสามารถนำแนวทางนี้ไปพัฒนาและต่อยอดให้กับสัตว์ปีกสายพันธุ์อื่นทั้งขนาดเล็กและใหญ่ได้ในอนาคต พร้อมทั้งชี้ให้เห็นถึงบทบาทของการผลิตแบบดิจิทัลในการยกระดับคุณภาพการรักษาด้านสัตวกรรมตกแต่งในสัตว์ และการส่งเสริมสวัสดิภาพสัตว์อย่างเป็นรูปธรรม

คำสำคัญ: ปากเทียม เทคโนโลยีการพิมพ์ 3 มิติ การฝังวัสดุฝังเทียม นกฟอส จงอยปากบน

Introduction

In recent years, the Pacific parrotlet (*Forpus coelestis*) has become one of the most popular small-sized companion parrot species, favored for its intelligence, manageable size, and engaging personality. As the human-animal bond deepens in modern households, birds are increasingly regarded as cherished family members rather than traditional pets. This shift has led to greater emotional investment and higher standards in veterinary care, especially when it comes to preserving the quality of life following traumatic injuries. Due to their small stature, Pacific parrotlets, commonly kept in captivity, are particularly susceptible to injuries when housed with larger birds. Beak trauma is a common problem in the companion parrot. Beak injury most often occurs secondary to bird

bites, other forms of aggression, or predator bites (Emily and Eisner 2021). The bird's beak (rhamphotheca) consists of two primary components: the upper beak or rhinotheca, and the lower beak or gnathotheca (Figure 1). These keratinized structures overlay a bony core and are essential for a wide array of natural behaviors. The avian beak plays a critical role in feeding, preening, object manipulation, climbing, and even locomotion (Doneley 2021; Lessner et al., 2023; Dickinson et al., 2024). However, if more than two-thirds of the beak, especially near the base, is lost, the germinal epithelium responsible for keratin regeneration is usually damaged, resulting in permanent structural loss (Matta et al., 2022). In such cases, the bird may become unable to perform basic natural behaviors, posing serious welfare concerns (Tokita 2003).

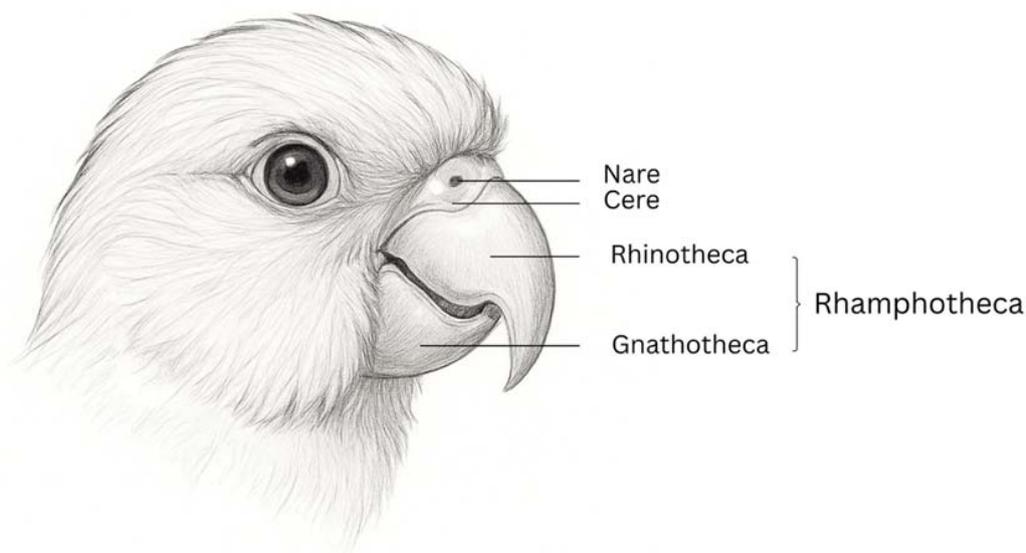


Figure 1. Anatomical illustration of the rhamphotheca in a Pacific parrotlet (*Forpus coelestis*).

Over the past decade, numerous prosthetic techniques have been developed to restore beak function in avian species. Materials used have ranged from dental acrylics, metal implants, toy plastic components, and 3D-printed constructs (Steenkamp 2014; Emily and Eisner 2021). In Amazon parrots (*Amazona oratrix*), cold-curing acrylic

resin combined with improvised metal scaffolding has been successfully applied to restore rostral maxillary fractures, demonstrating functional recovery and structural integrity with long-term follow-up (Matta et al., 2022). Additionally, a report by Panelli Marchio et al. (2022) showed the successful application of acrylic prostheses in five species: a

roadside hawk (*Rupornis magnirostris*), a cockatiel (*Nymphicus hollandicus*), turquoise-fronted parrots (*Amazona aestiva*), and a maritaca (*Pionus maximiliani*). These birds received rhinothecal reconstructions using cold-curing acrylic resin and showed positive outcomes without complications during follow-up (Panelli Marchio et al., 2022). Furthermore, resourceful adaptations have been reported in smaller parrots. A green-cheek conure (*Pyrrhura molinae*) underwent remote-guided beak reconstruction using a prosthetic made from a plastic toy bird, demonstrating the feasibility of telemedicine-assisted avian surgery in low-resource environments (Patel 2021). In a great hornbill (*Buceros bicornis*), a 3D-printed prosthesis was designed and fitted to replace a damaged casque due to squamous cell carcinoma, marking a landmark application of additive manufacturing in avian craniofacial restoration (Xie et al., 2019). A similar technique was later used in an Oriental stork (*Ciconia boyciana*) with successful results (Kim et al., 2023). However, these cases have typically involved medium- to large-sized parrots, with no documented prosthetic application in the Pacific parrotlet, in which the small size presents unique anatomical and mechanical challenges. Prosthetic beak reconstruction in avian species involves multiple interdependent factors, including the prosthesis material, fixation technique, and postoperative care. Cold-curing acrylic resin offers the advantage of being lightweight and well-tolerated; however, it requires intraoperative sculpting, which may lengthen anesthesia time. Pre-formed components, such as those adapted from plastic toys, can reduce operative time and demonstrate creative adaptability, though achieving a precise anatomical fit and versatile fixation options may be challenging. Metal implants provide rigidity but may be limited by weight and installation space, particularly in small psittacine species. Advances in three-dimensional (3D) printing now allow for

pre-fabricated, species-specific prostheses that combine weight optimization with tailored fixation designs, potentially reducing surgical time and improving functional outcomes. Such approaches build upon the strengths of previous techniques while addressing the anatomical and mechanical challenges unique to smaller birds, including the Pacific parrotlet.

In this case, a 3D-printed prosthesis for upper beak reconstruction was selected for its superior customizability, precision, biocompatibility, and lightweight properties (Shilo et al., 2018). The advent of 3D printing in veterinary medicine has revolutionized prosthetic development by enabling the creation of patient-specific devices with optimal anatomical conformity, enhanced structural integrity, and reduced fabrication time (Xie 2019; Kim et al., 2023). The ability to digitally scan, model, and produce a customized prosthesis allows for a more accurate fit and improved surgical outcomes, particularly in small avian patients where anatomical variation and size constraints present significant challenges. This report presents the first documented case of a 3D-printed upper beak prosthesis surgically affixed to a parrotlet with complete upper beak loss due to trauma. The objective is to demonstrate the feasibility of applying 3D-printed prosthetics to tiny avian species and to provide a clinical reference for future cases involving beak loss in miniature parrots.

Case description

Case background and clinical indication

A female Pacific parrotlet presented with complete upper beak loss due to a bite from another bird (Figure 2). The injury occurred on the same day, and the bird was brought in for evaluation immediately thereafter. On initial examination, the bird was unable to grasp or manipulate

food, and the beak injury appeared as an open wound with exposed soft tissue. The bird was treated with ceftiofur crystalline free acid (EXCEDE™, Zoetis LLC., U.S.A.) 50 mg/kg intramuscularly every 4 days, for 2 doses for infection control, and 1 dose of robenacoxib (Onsior™, Bela-Pharm GmbH & Co. KG, Vechta, Germany) 10 mg/kg intramuscularly for analgesia and anti-inflammatory support. Due to the bird's inability to feed independently, force feeding with a commercial hand-feeding formula was initiated using a syringe with a feeding tube to ensure adequate caloric intake during the recovery period. This supportive care helped stabilize the patient's body condition,

prevent further metabolic decline, and wound contamination by food. Over the course of approximately one month, the wound underwent gradual epithelialization, with sloughing of necrotic tissue and the development of a healthy granulation bed, rendering the site suitable for prosthetic application. Given that the extent of the beak loss exceeded the regenerative capacity of the germinal epithelium, spontaneous regrowth was deemed impossible. Surgical implantation of the prosthesis was therefore planned and carried out approximately one month after the injury to restore prehension and improve long-term welfare.



Figure 2. Complete upper beak loss in a female Pacific parrotlet (*Forpus coelestis*) due to a traumatic injury.

Prosthesis design and fabrication

Anatomical references were obtained from a healthy Pacific parrotlet that had died of natural causes. Anatomical data were collected using the MyVet CTi3D computed tomography (CT) scanner, a cone-beam CT system tailored

for veterinary use. It offers high-resolution 3D imaging with lower radiation doses and a fast scanning time, making it suitable for small exotic animals and reducing motion artifacts during imaging (MyVet Imaging 2025). The acquired stack of 2D DICOM CT images (Figure 3A)

was then imported into 3D Slicer (version 5.6.1), an open-source medical image processing platform. In this step, threshold-based segmentation and manual refinement were performed to isolate the beak and craniofacial structures from surrounding tissues. The software's volume rendering function was then used to reconstruct a high-resolution 3D anatomical model (Figure 3B), enabling precise visualization of the beak's morphology and dimensions. The segmented beak region from a morphologically intact specimen was exported in STL format and imported into Nomad Sculpt (version 2.2), a three-dimensional computer-aided design (CAD) application. Within Nomad, the intact beak was digitally separated from the head model to serve as a morphological reference template for the prosthetic design. This template was then adapted to incorporate features for a wiring attachment technique (Figure 3C), ensuring secure fixation. Using an

anatomically accurate beak as the starting reference allowed the prosthesis to replicate the natural curvature, occlusion, and proportional dimensions of the original beak with high fidelity.

The prosthetic beak was fabricated using stereolithography (SLA) 3D printing with standard photopolymer resin. After printing, the beak was post-cured under ultraviolet (UV) light at 60°C for 30 minutes. To enhance mechanical durability and biocompatibility, the printed prosthesis was coated with a flowable dental composite resin. Examples of the 3D-printed prosthetic beaks are shown in Figure 4. This preoperative fabrication approach allows the prosthesis to be prepared in advance, significantly reducing operative time during surgery. As a result, it improves surgical efficiency and minimizes physical stress on the animal.

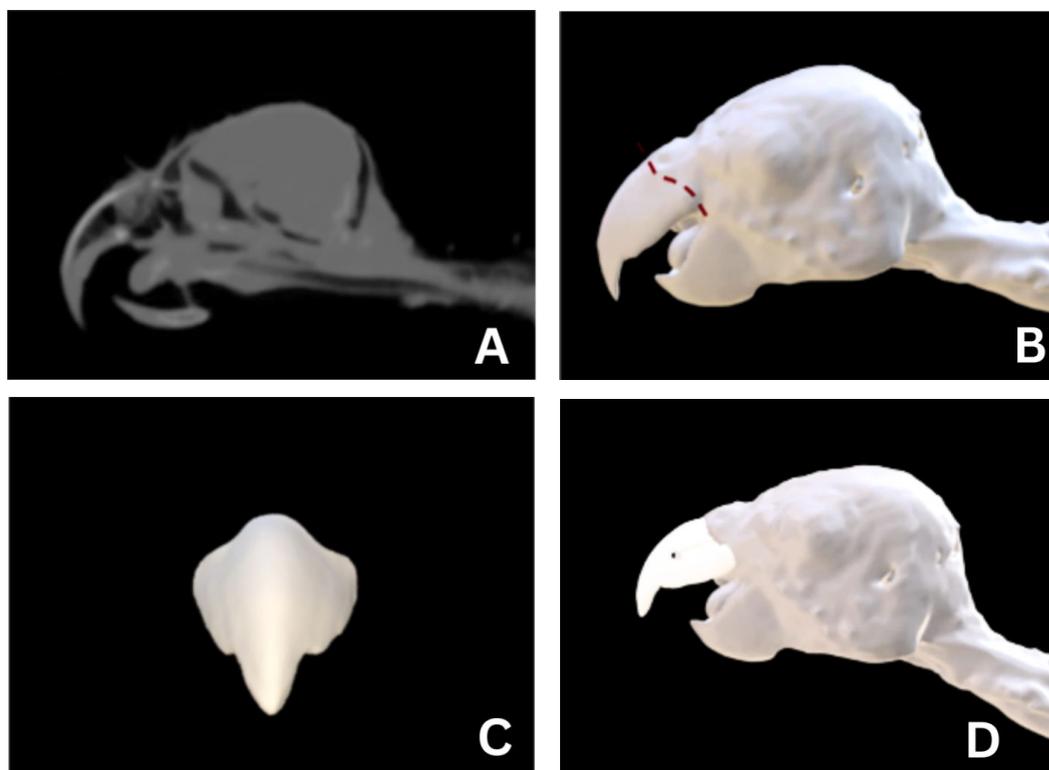


Figure 3. Workflow of prosthetic beak fabrication. (A) CT scanning of a Pacific parrotlet head using MyVet CTi3D. (B) 3D anatomical model reconstructed from CT images. The red dashed lines indicate the segmentation region. (C) Digital reconstruction of the beak geometry and (D) final prosthesis design showing attachment integration.

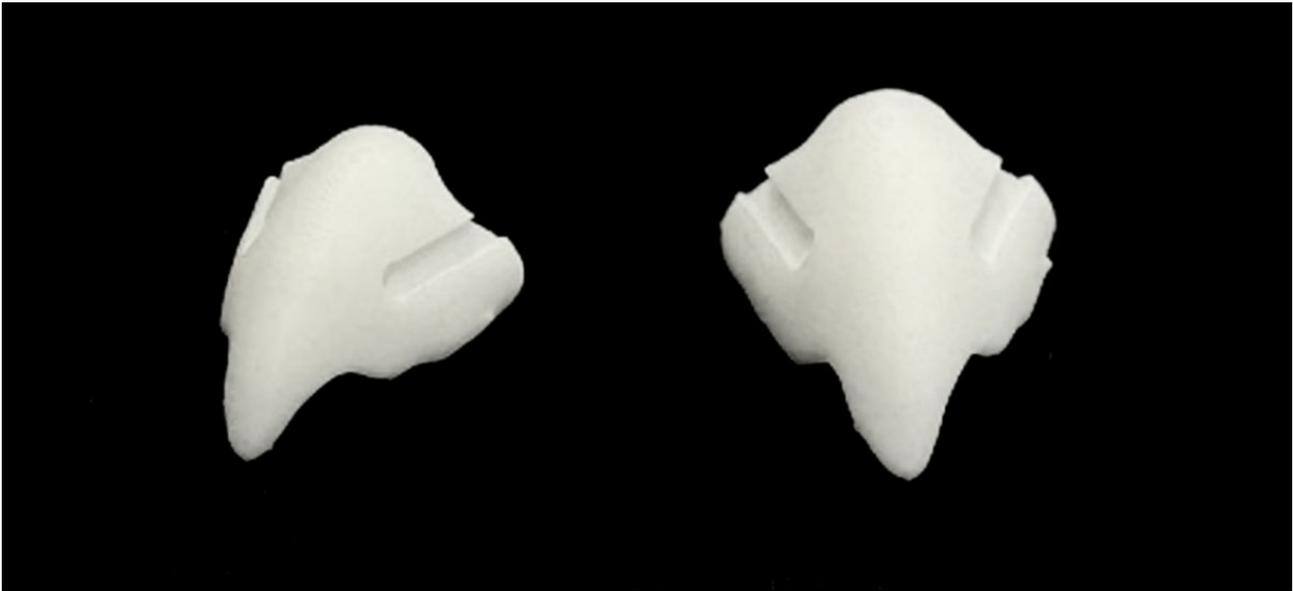


Figure 4. 3D-printed prosthetic beaks replicating natural morphology.

Surgical procedure and fixation technique

Prior to surgery, the patient underwent a thorough physical examination, with particular attention to the healing status of the soft tissue surrounding the cere and the rhinothecal implantation site. The area was assessed to ensure complete epithelialization and the absence of active inflammation or infection, both of which are prerequisites for prosthesis fixation. To minimize the risk of regurgitation under anesthesia or during restraint, food was withheld for approximately four hours preoperatively. Additionally, pre-oxygenation was performed to enhance oxygen reserves prior to induction.

The parrotlet was anesthetized via intramuscular injection into the pectoral muscle with midazolam (Midazolam-hameln®, Siam Bioscience Co. Ltd., Thailand) at a dose of 5 mg/kg and butorphanol (Butodol®, NEON LABORATORIES LTD., India) at a dose of 0.6 mg/kg intramuscularly, providing deep sedation and analgesia. After confirming the onset of anesthesia, the patient was stabilized for the procedure. Throughout the operation, the bird was gently restrained by a trained veterinary nurse to facilitate

multi-angle manipulation of the head and beak. This hands-on technique was essential, as fixation of the prosthesis required access from multiple angles and could not be accomplished with the bird held in a single static position. If the lower beak was found to be overgrown, it was carefully trimmed to the appropriate length using a pliers-type nail clipper to achieve proper alignment with the upper beak, and the excised portion was discarded in a biohazard container.

The oral cavity and cere were then cleaned to remove mucus and debris. A disinfectant containing hypochlorous acid was applied to the surgical area to minimize infection risk (Figure 5). A dental orthodontic micro implant, specifically a self-tapping mini screw made of titanium alloy (1.4 x 6 mm) was inserted into the midline of the remaining rhinotheca to serve as a mechanical anchor for prosthetic fixation (Figure 6).

To secure the prosthetic beak, a 25G x 5/8" hypodermic needle was passed laterally through the cranial region from left to right, at a site midway between the medial canthus and the base of the rhinotheca. A 0.2 mm

stainless steel dental wire was threaded through the needle, which was then withdrawn, leaving the wire in place (Figure 7). The wire was guided through designated holes in the prosthetic beak, which was then positioned anatomically over the skull. The wire was twisted to secure the prosthesis tightly in place, trimmed, and its ends were bent and tucked into a recessed groove within the prosthesis for additional stability and comfort (Figure 8).

To further secure the structure and improve biocompatibility, a flowable dental composite resin (DENTEX®, Dentex Co., Ltd, China) was applied around the wire entry points and cured with ultraviolet (UV) light (Figure 9). Additional resin was used to reinforce wire stability and enhance the aesthetic appearance. The entire

surgical process, from anesthetic induction to completion of prosthetic fixation, was completed within approximately 15 minutes, minimizing anesthesia duration and associated risk.

Anesthesia was reversed using 0.03 ml of Flumazenil (Flumazenil®, HIKMA FARMACÊTICA, Portugal) at a dose of 0.1 mg/kg, administered intramuscularly into the pectoral muscle. Postoperative monitoring was conducted until the bird fully regained consciousness and exhibited stable vital signs (Figure 10). In this case, a CT scan was performed after recovery for illustrative purposes to visualize the positioning of the prosthesis and surrounding craniofacial structures (Figure 11). However, this imaging step is not routinely included in the standard clinical protocol.

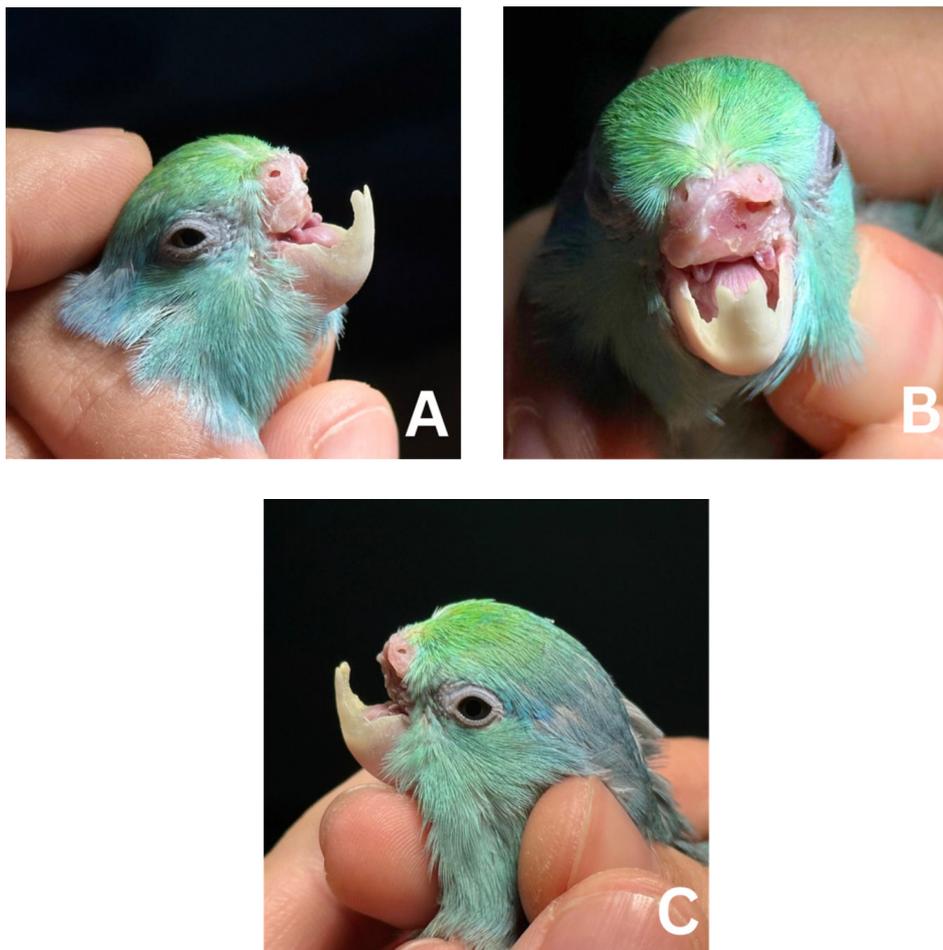


Figure 5. Preoperative views of the cleaned cere and oral cavity with healthy granulation tissue. (A) Right lateral view, (B) frontal view, and (C) left lateral view.



Figure 6. A titanium alloy orthodontic miniscrew was inserted into the midline of the remaining rhinotheca to serve as a mechanical anchor for prosthetic fixation.

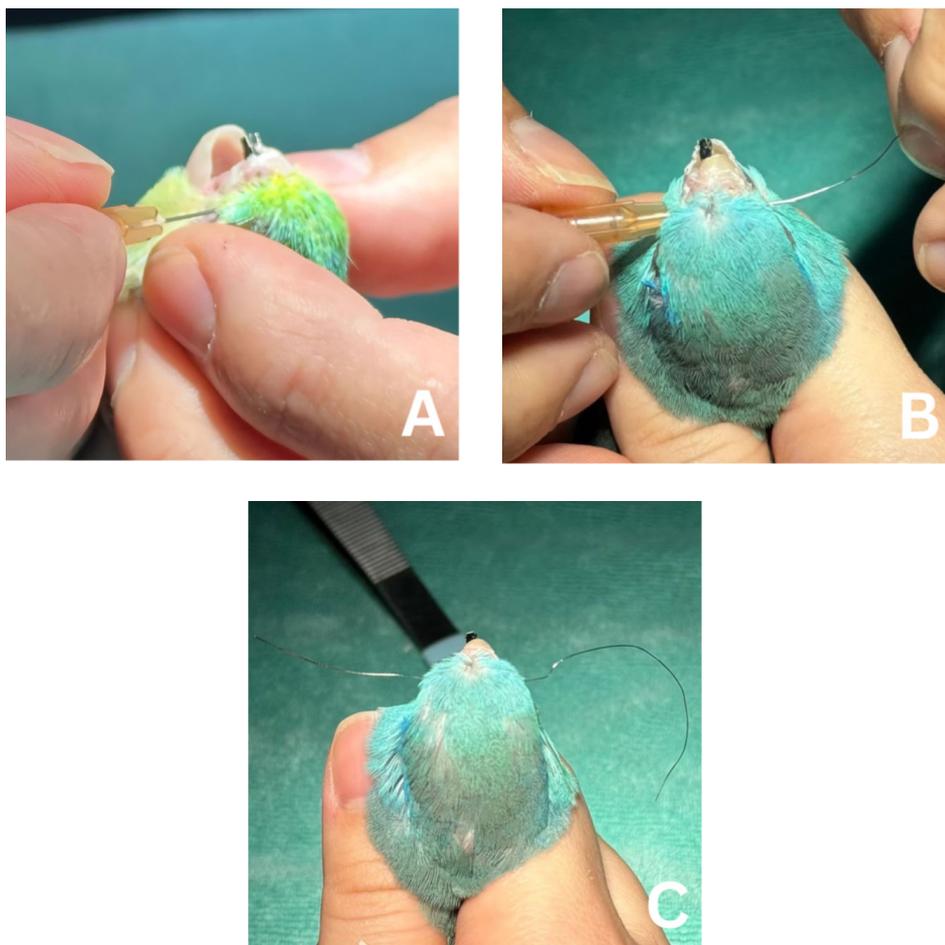


Figure 7. A 25G hypodermic needle was used as a guide (A) to pass a 0.2 mm stainless steel wire transversely through the cranial region, between the medial canthus and the base of the rhinotheca (B, C).

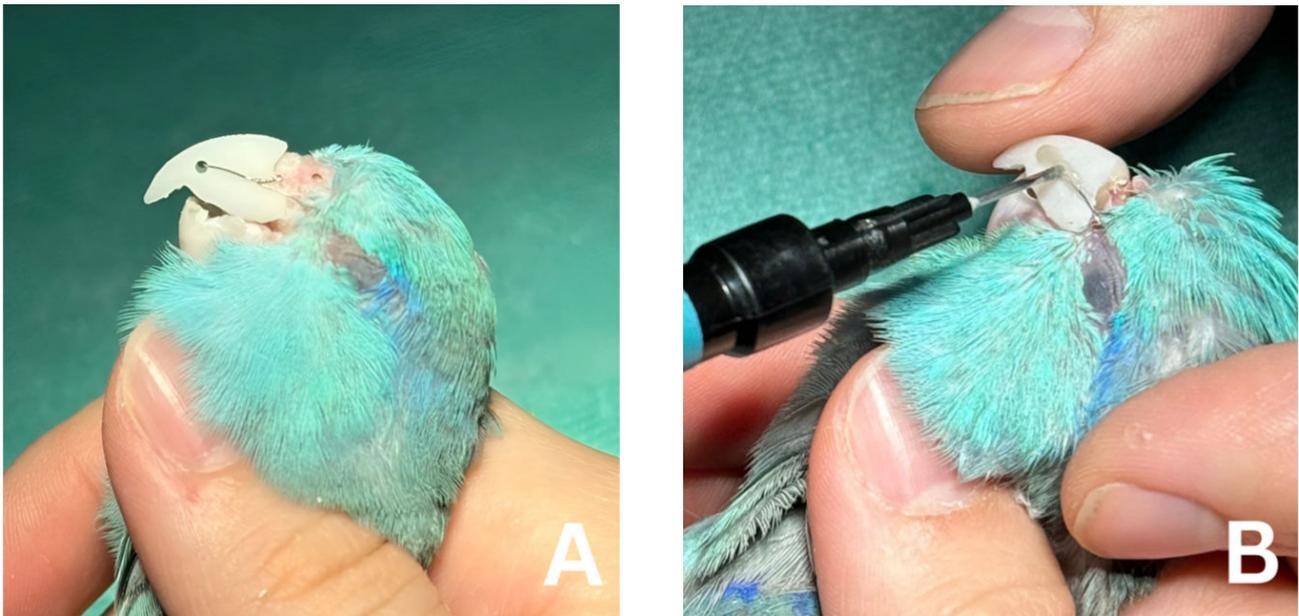


Figure 8. The stainless-steel dental wire was twisted and tucked into the prosthesis groove for stabilization (A), followed by application of flowable dental composite resin to seal the wire entry points and enhance biocompatibility (B).



Figure 9. Ultraviolet (UV) light was applied to cure the flowable dental composite resin around the wire entry points.



Figure 10. Completed assembly of the 3D-printed upper beak prosthesis in a Pacific parrotlet (*Forpus coelestis*) following surgical fixation.

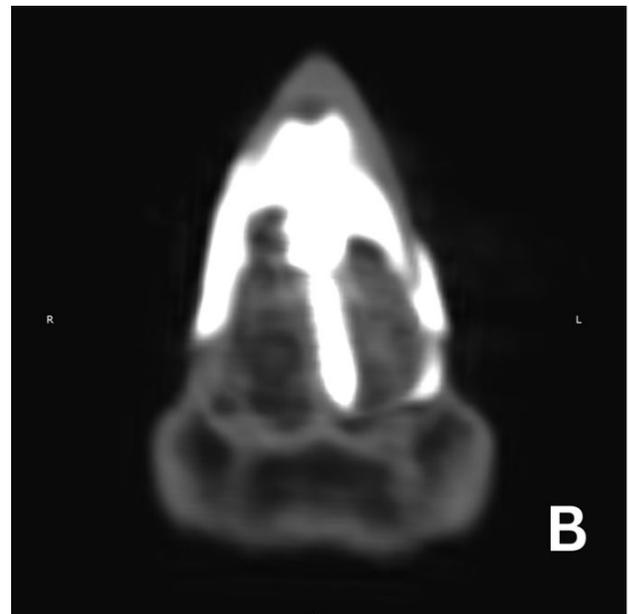
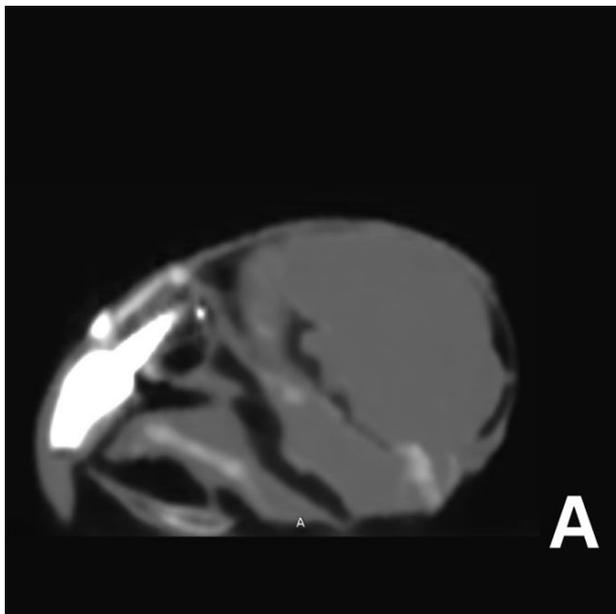


Figure 11. Postoperative CT images of the parrotlet's head after prosthesis placement. (A) Sagittal view and (B) dorsal view show the mini screw anchored solely within the remaining rhinotheca, without penetrating the supraorbital sinus.

Due to the anatomical proximity of the beak base to critical structures such as the nares and the supraorbital sinus, specific precautions were taken during surgical fixation. First, care was exercised when placing the titanium miniscrew to avoid penetrating the supraorbital sinus, which could lead to intracranial complications. Second, during the application of flowable dental composite resin, the material was precisely confined to the prosthesis interface, ensuring that it did not overflow and obstruct the nares or airway. Lastly, the surgical team closely monitored intraoperative bleeding from the wound edges to prevent blood aspiration, especially given the bird's small airway size. These measures collectively minimized surgical risk and supported a safe, complication-free procedure.

Postoperative care and outcome

Following surgical implantation of the 3D-printed upper beak prosthesis, the bird recovered uneventfully from anesthesia and showed no signs of acute discomfort or prosthesis instability. During the first postoperative week, the owner was advised to limit the parrotlet's activity by confining it to a smaller enclosure and placing food dishes at floor level to minimize climbing behavior. This environmental adjustment helped promote secure integration of the prosthesis by limiting excessive use of the beak during early healing. By postoperative day 3, the bird began self-feeding on soft food and demonstrated progressive improvement in functional use of the prosthetic beak. Throughout the first several months, the prosthesis remained stable and enabled the bird to perform essential behaviors such as grooming, perching, and interacting with its environment. Although the bird was unable to consume hard-shelled seeds, it maintained adequate nutrition on a soft food diet and crushed seeds prepared by the owner.

Due to the lack of natural beak-to-beak wear mechanisms typically provided by contact between the upper and lower beak, routine maintenance was necessary to prevent overgrowth of the lower beak. The owner was instructed to perform trimming of the lower beak every 1-2 weeks to maintain proper alignment and prevent excessive pressure or misalignment against the prosthesis, which could result in loosening or material deformation.

At approximately one year postoperatively, granulation tissue developed at the interface between the prosthesis and the cere, gradually exerting pressure that led to partial loosening of the implant (Figure 12). The prosthesis was electively removed to allow soft tissue recovery. A follow-up CT scan was performed after implant removal to evaluate the condition of the remaining rhinotheca and adjacent structures. The scan revealed insufficient rhinothecal structure to support re-implantation. The cere showed signs of hyperepithelialization at the contact area; however, the nare remained patent with no obstruction, and the bird maintained normal respiration (Figure 13). Despite the removal, the bird maintained satisfactory body condition with no signs of distress or nutritional deficiency, as the owner continued supportive feeding using a soft diet and hand-rearing formula.

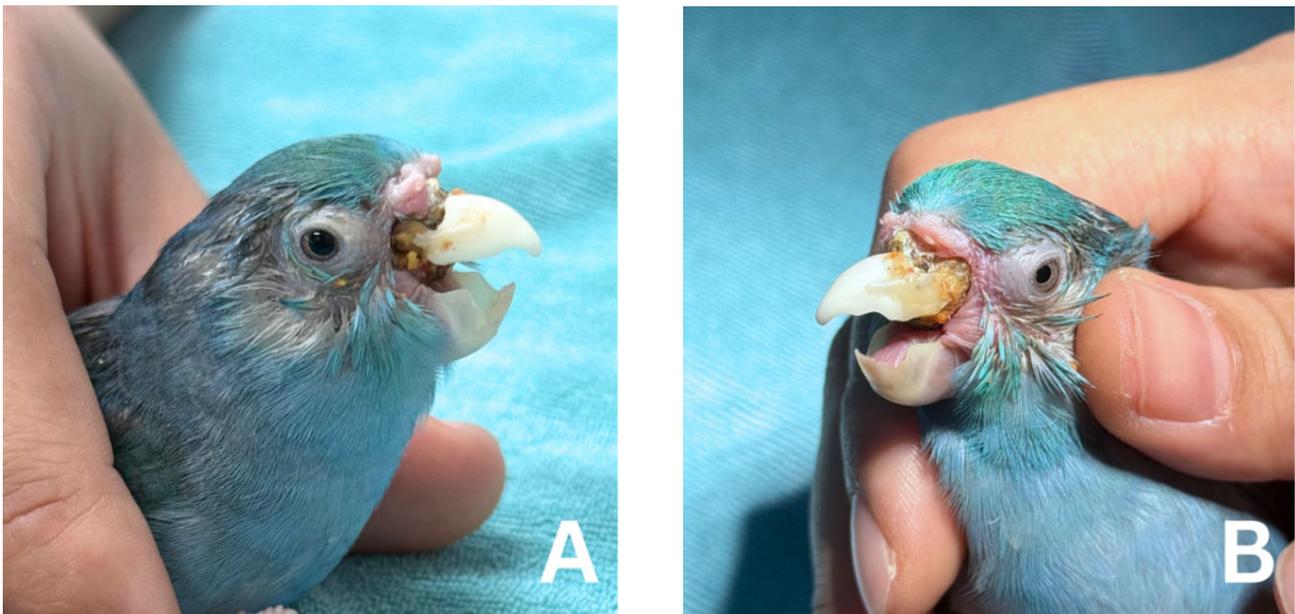


Figure 12. Right (A) and left (B) lateral views at one year postoperatively, showing granulation tissue formation at the prosthesis and cere interface, resulting in gradual displacement and partial loosening of the implant.

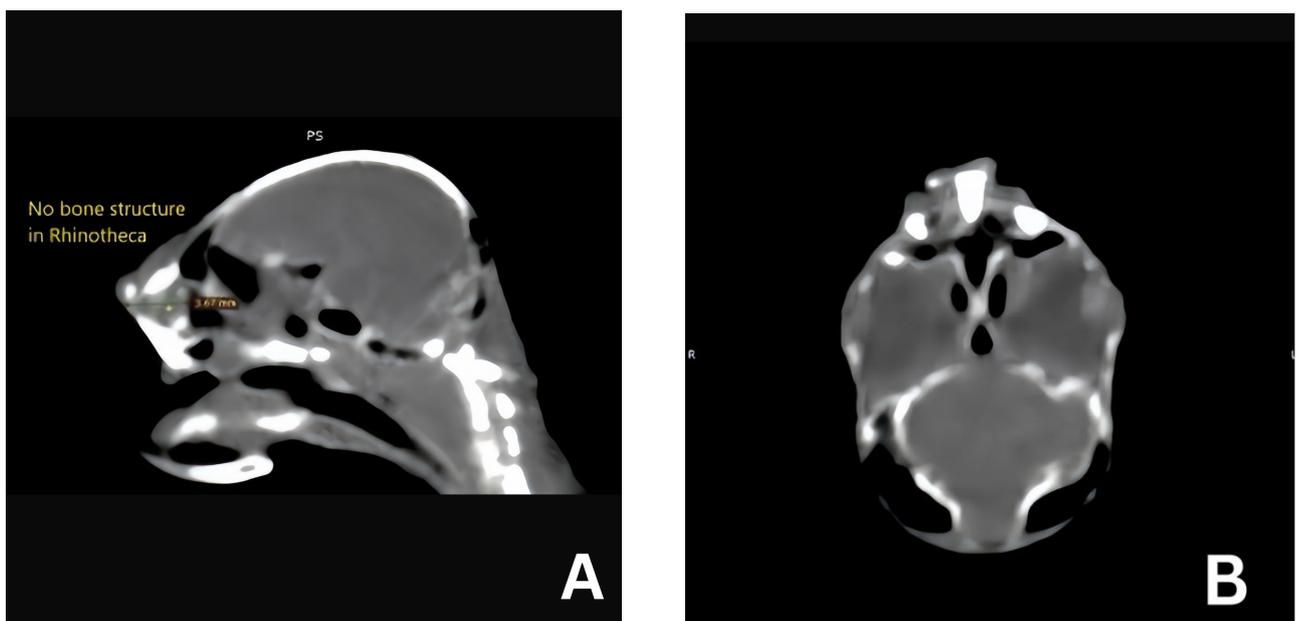


Figure 13. CT-scan images after prosthesis removal. (A) sagittal view shows insufficient rhinothecal bone for reattachment and cere hyperepithelialization. (B) Dorsal view confirms patent sinus with no obstruction.

At 8 months after implant removal, the bird was observed consuming ground pellet food independently, as shown in Figure 14, while still receiving supplemental hand-rearing formula from the owner. Although the prosthesis had been removed, its temporary placement

allowed the bird to regain natural behaviors for example pecking and preening during the period it was in place. This underscores the functional significance of prosthetic intervention in restoring natural behavior and improving quality of life, even if only temporarily.



Figure 14. A Pacific parrotlet (*Forpus coelestis*) observed consuming ground pellet food independently eight months after prosthesis removal.

Discussion

This report presents the first documented clinical application of a 3D-printed upper beak prosthesis in a Pacific parrotlet, representing a promising advancement in avian reconstructive surgery. While similar interventions have been described in larger birds, including Amazon parrots (*Amazona oratrix*) (Matta et al., 2022), cockatiels (*Nymphicus hollandicus*) (Panelli Marchio et al., 2022), and green-cheeked conures (*Pyrrhura molinae*) (Patel 2021), the application in small psittacines remains rare due to anatomical and biomechanical challenges. Conventional methods such as the use of metal scaffolds, dental acrylics,

or improvised materials have been associated with poor anatomical matching, instability, and limited biocompatibility, particularly in miniature species (Steenkamp 2014; Emily and Eisner 2021). Notably, in some reports, the post-operative follow-up period is limited or lacks detailed outcome assessment, with few providing clear data on prosthesis longevity. However, Panelli Marchio et al. (2022) reported prosthetic stability up to 15 months without complications, suggesting promising long-term feasibility.

In this case, the use of a stereolithographically printed prosthesis allowed for accurate anatomical restoration and resulted in a lightweight, durable, and biocompatible

design. These features are critical in smaller birds, where craniofacial load bearing must be minimized. The prosthesis was carefully designed to fit over the residual rhinotheca, preventing direct contact between uncured photopolymer resin and soft tissues. To further enhance biocompatibility, a dental composite resin barrier was applied at the interface, reducing the risk of irritation while simultaneously improving the prosthesis's mechanical integration and surface finish.

The entire implantation procedure, including prosthesis fitting, fixation with a titanium miniscrew and dental wire, and composite resin application, was completed within approximately 15 minutes. This reduced surgical and anesthetic time, which is especially important in small avian species like parrotlets that have high metabolic rates and are prone to anesthetic-related complications (Young et al., 2022). By combining customized preoperative planning with a rapid and secure fixation method, this approach offers a clinically valuable, efficient, and welfare-oriented solution. Furthermore, its adaptability may support broader applications in both small and large avian species requiring beak reconstruction.

From a biomechanical perspective, the bird's recovery reflected a rapid and successful adaptation. By the third postoperative day, the parrotlet was able to consume soft food independently and perform essential behaviors such as food manipulation and perching, suggesting strong neuromuscular adaptability and initial prosthesis integration. However, the artificial surface of the prosthetic beak

lacks the friction properties of natural keratinized tissue, preventing normal wear-based regulation of the lower beak. As a result, mandibular overgrowth can occur, which may lead to mechanical stress, dorsal displacement, or loosening of the prosthesis. To mitigate these risks, routine lower beak trimming is essential (Harcourt-Brown 2023). In this case, the owner was instructed to perform trimming at home every 1-2 weeks to maintain proper occlusion and reduce mechanical loading on the prosthesis. Veterinary teams should highlight the importance of this long-term maintenance during postoperative counseling and provide guidance on monitoring growth and trimming techniques. Regular follow-up appointments may also be necessary to ensure the prosthesis remains stable and functional over time.

Approximately one year post-surgery, the prosthesis began to show signs of loosening, likely due to granulation tissue formation at the interface with surrounding soft tissue. This may have been influenced by repeated mechanical stress during feeding and grooming, which gradually displaced the prosthesis dorsally. As a result, elective removal was performed to avoid further complications. While several previous case reports have demonstrated successful application of prosthetic beaks, most have reported outcomes within short- to medium-term periods, typically spanning a few weeks to several months (Patel 2021; Matta et al., 2022; Kim et al., 2023). Longer-term retention has been mentioned in some cases. For instance, Marchio et al. (2022) reported a 15-month duration, but they often lack comprehensive documentation of tissue responses or

post-removal outcomes. In contrast, the present case provides both functional and clinical follow-up data over the course of nearly one year, offering important insight into the medium-term viability and biological interaction of a 3D-printed prosthesis in a small psittacine species. These findings highlight the potential of this technique for welfare improvement and emphasize the need for continued refinement in prosthesis design and fixation methods to achieve longer-lasting outcomes across avian species of varying sizes.

Currently, there are no standardized criteria for selecting candidates for prosthetic beak implantation. Rather than relying on strict eligibility guidelines, each case is carefully evaluated on an individual basis. Our primary consideration is the potential to improve the bird's quality of life. In situations where the natural beak is lost beyond the point of regeneration, providing a functional prosthesis, even if temporary, offers the bird a chance to regain fundamental behaviors such as feeding and object manipulation. From our perspective, choosing not to attempt reconstruction would mean the patient remains permanently without a beak, and thus without the possibility of regaining normal function. Therefore, we strive to develop tailored approaches that suit the specific anatomical and clinical conditions of each patient.

Despite this success, we must acknowledge certain limitations. As a single-case study, generalizability remains limited. The technique relies on access to advanced imaging (CT), digital modeling software, and 3D printing equipment

not readily available in all veterinary facilities. Furthermore, while the materials used were well tolerated in this case, longer-term evaluations, including histological assessments, are needed to better understand prosthesis-tissue interaction and risks such as stress accumulation or micromotion at fixation sites.

We developed a set of prefabricated 3D-printed prosthetic beaks based on anatomical references to address these practical limitations and promote wider clinical applicability. These include size variations ranging from -10%, -5%, 0%, +5%, to +10% relative to the standard upper beak dimensions of the Pacific parrotlet. This library of ready-to-use prosthetic beaks enables veterinarians to select the most anatomically suitable size without requiring case-specific CT imaging or in-house 3D printing facilities. Moreover, these standardized prostheses have been made available to partner veterinary hospitals, accompanied by workshops and surgical training seminars hosted by our team. These initiatives aim to disseminate the knowledge and practical skills required for successful prosthetic beak implantation, ensuring that this innovation can be applied in real-world settings and ultimately improve the welfare of more avian patients.

Future improvements in prosthesis fixation would also benefit from closer interdisciplinary collaboration with veterinary biomedical engineers. Such cooperation could lead to more refined designs, materials, and fixation methods tailored to the anatomical and functional needs of avian patients, thereby enhancing the longevity of the prosthesis and advancing animal welfare.

Conclusion

In conclusion, this case provides compelling evidence for the viability of 3D-printed prosthetics in small avian patients and paves the way for broader clinical adoption. With appropriate refinements and increased accessibility to digital fabrication technologies, this approach could evolve into a standard of care for avian beak reconstruction. This surgery may not have been complex or dramatic, but its impact was profound. A bird that once could not eat, climb, or groom was given the chance to live normally again. The 3D-printed beak was not just a prosthetic, it was a restoration of function, freedom, and dignity. This work may not change the world. But for this one parrotlet, the world changed completely.

Acknowledgements

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Surgical Management of Femorotibial Joint Luxation with Hinged Transarticular External Fixation in a Blue-and-Gold Macaw (*Ara ararauna*): A Case Report

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Abstract

This case report discusses hinged transarticular external fixation to manage femorotibial joint luxation in a blue-and-gold macaw (*Ara ararauna*), emphasizing the relative infrequency and complexity of this orthopedic challenge in avian medicine. An 11-year-old macaw was presented to the exhibit with acute non-weight-bearing of the right leg and associated joint swelling for three days following trauma. Conservative management alone was inadequate to restore joint stability and function due to anatomical factors, necessitating surgical intervention. The surgical technique utilizing a Fixateur Externe du Service de Santé des Armées (FESSA) hinged linear transarticular external fixator (HLTEF), was appropriate for the femorotibial joint's anatomical and biomechanical aspects of the avian species. Providing stabilization of the femorotibial joint and restricting the range of motion is crucial for preserving joint and muscle function. After the surgery, the macaw showed a good recovery without complications. The external fixator remained stable, enabling the bird to perch. The external fixator was removed after three weeks. Six months postoperatively, the macaw demonstrated normal utilization of its leg, with no evidence of recurrent joint dislocation and full functional recovery.

Keywords: Avian, Orthopedics, Transarticular, External fixation

รายงานสัตว์ป่วย: การใช้การตรึงภายนอกแบบบานพับที่ระหว่างข้อต่อเพื่อรักษาข้อเคลื่อนหลุดบริเวณข้อเข่าในนกแก้วบลูแอนด์โกลด์มาคาว์

สุทธิดา ทองอินทร์¹ ศศิวิมล แซ่ลิ้ม¹ จุฬารัตน์ ธีรตันติกุล¹ เบนจพล หล่อสัญญาลักษณ์^{1,2*}

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บทคัดย่อ

รายงานกรณีศึกษา นำเสนอแนวทางการรักษาภาวะข้อเข่าเคลื่อนหลุดในนกแก้วบลูแอนด์โกลด์มาคาว์ ด้วยการตรึงภายนอกแบบบานพับที่ระหว่างข้อต่อ โดยนกมาคาว์เพศผู้ อายุ 11 ปี ได้เข้ารับการตรวจรักษาเนื่องจากอาการไม่สามารถลงน้ำหนัก ขาขวา ร่วมกับอาการบวมของข้อ ซึ่งเกิดขึ้นภายหลังการเกิดอุบัติเหตุเป็นระยะเวลา 3 วัน การรักษาเบื้องต้นด้วยวิธีการประคบประคอง อันประกอบด้วยการดึงข้อให้เข้าที่ การพัก และการให้ยาต้านการอักเสบ ไม่สามารถฟื้นฟูการทำงานและความมั่นคงของข้อต่อได้ จึงพิจารณาให้ทำการรักษาด้วยวิธีการผ่าตัด ในการผ่าตัด ได้เลือกใช้อุปกรณ์ Fixateur Externe du Service de Santé des Armées (FESSA) ร่วมกับอุปกรณ์ตรึงภายนอกแบบบานพับ เพื่อให้สอดคล้องกับลักษณะทางกายวิภาคและชีวกลศาสตร์ที่จำเพาะของข้อเข่าในนก วิธีการดังกล่าวนี้ มุ่งเน้นการสร้างความมั่นคงให้แก่ข้อต่อ พร้อมทั้งคงไว้ซึ่งช่วงการเคลื่อนไหวที่เหมาะสมระหว่างการฟื้นตัวของข้อ ภายหลังจากผ่าตัด นกมีการฟื้นตัวที่ดี โดยไม่พบภาวะแทรกซ้อนที่รุนแรง เครื่องยึดติดภายนอกมีความมั่นคงและช่วยให้สามารถเกาะคอนได้ มีการถอดเครื่องยึดติดภายนอกเมื่อครบ 3 สัปดาห์ และภายหลังจากผ่าตัดเป็นเวลา 6 เดือน พบว่า นกมาคาว์สามารถกลับมาใช้งานขาได้เป็นปกติ โดยไม่มีภาวะข้อเคลื่อนหลุดซ้ำ

คำสำคัญ: นก สัตยกรรมกระดูก ระหว่างข้อต่อ การตรึงภายนอก

Introduction

In avian species, the femorotibial joint serves as the weight-bearing element of the stifle, facilitating flexion and extension of the crus with restricted rotation (Harris et al., 2007). Femorotibial joint luxation is prevalent in avian species (Azmanis et al., 2014). Luxation, or dislocation, refers to the complete displacement of a bone from a joint with no contact between the two articular surfaces (Simonis et al., 2024). In avian species, femorotibial joint luxation typically results from trauma; specifically, direct injury to the surrounding soft tissues compromises its stabilizing structures, leading to abnormal adduction or rotation of the limb (Bowles and Zantop 2002). Moreover, the muscular contraction frequently noted after dislocation may obstruct its rectification. Injury to muscles and nerves can result in paresis or paralysis of the limb, causing difficulties with ambulation, perching, or gripping (González 2009).

The therapeutic modalities for femorotibial joint luxation include external coaptation and surgical intervention. External coaptation alone carries significant disadvantages. In many species, especially psittacine birds (Simonis et al., 2024), the presence of the inguinal web, located in the ventral region of the thigh where the leg joints the body at the femur, complicates the procedure as it nearly reaches the level of the stifle (González 2009). This restricts the external coaptation's ability to extend proximally over the femorotibial joint, leading to a bandage that functions as a fulcrum if improperly positioned (Simonis et al., 2024). Therefore, these limitations often necessitate surgical intervention.

Surgical intervention in avian species predominantly employs external skeletal fixation utilizing a FESSA system. The FESSA (Fixateur Externe du Service de Santé des Armées) is a lightweight external skeletal fixator intended for intricate fractures of the hands and feet in human

medicine (Hatt et al., 2007). The hinges comprise two separate elements connected by a screw. The maximum attainable angle is 180 degrees, whereas the minimum is roughly 40 degrees (Azmanis 2011). Consequently, the FESSA system was suitable for avian species.

The previous example reports used external fixation with open joint reduction and co-fixation. One, the blue-and-gold macaw described an open femorotibial joint reduction stabilized with transarticular pins from the proximal tibiotarsus to the distal femur, secured with bone cement as a bridging bar, resulting in arthrodesis of the right femorotibial joint and an acceptable outcome (Simonis et al., 2024). Another study, the surgical approach for the pigeons right femorotibial joint, involves fixing the artificial lateral collateral ligament, followed by applying the FESSA hinged linear external skeletal fixator (Azmanis 2011). Postoperative outcomes and complications, including intracapsular and soft tissue damage leading to osteoarthritis and lameness, contribute to pododermatitis (Azmanis 2011).

The lack of data evaluating hinged external fixation as a standalone treatment highlights the need for further research to assess its efficacy and safety in different clinical settings. This case report presents the outcomes of using hinged transarticular external fixation as a primary surgical approach for managing femorotibial joint luxation in a blue-and-gold macaw, including preoperative management, surgical technique, postoperative care, and long-term follow-up. This study aims to contribute to the limited body of knowledge for this technique and explore its potential as a simple, minimally invasive, and effective treatment with favorable outcome.

Case description

Presentation and clinical findings

An 11-year-old, 1.1 kg male blue-and-gold macaw (*Ara ararauna*) was presented with a history of acute non-weight bearing on the right leg (Figure 1), with progressive joint swelling for three days following a suspected fall. The bird was reluctant to perch and demonstrated visible discomfort upon manipulating the affected limb.

Clinical examination revealed the right femorotibial joint to be swollen, with crepitus and instability upon manipulation, pain on palpation, and a positive deep pain

response. Radiographs revealed laxation of the right femorotibial joint with complete anterior dislocation, without any associated fractures, accompanied by soft tissue swelling (Figure 2).

The blood profile revealed that the morphology of red blood cells was normal. The morphology of white blood cells showed heterophil toxic granules present at a level of 1+ (100% toxicity). The estimated white blood cell count was $41.6 \times 10^6/\text{L}$. The packed cell volume was 36, the plasma protein level was 4.9, and the plasma exhibited a clear color (Table 1).

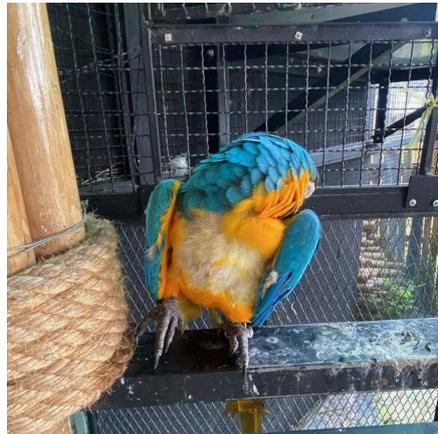


Figure 1. The macaw exhibited non-weight bearing on the right leg.

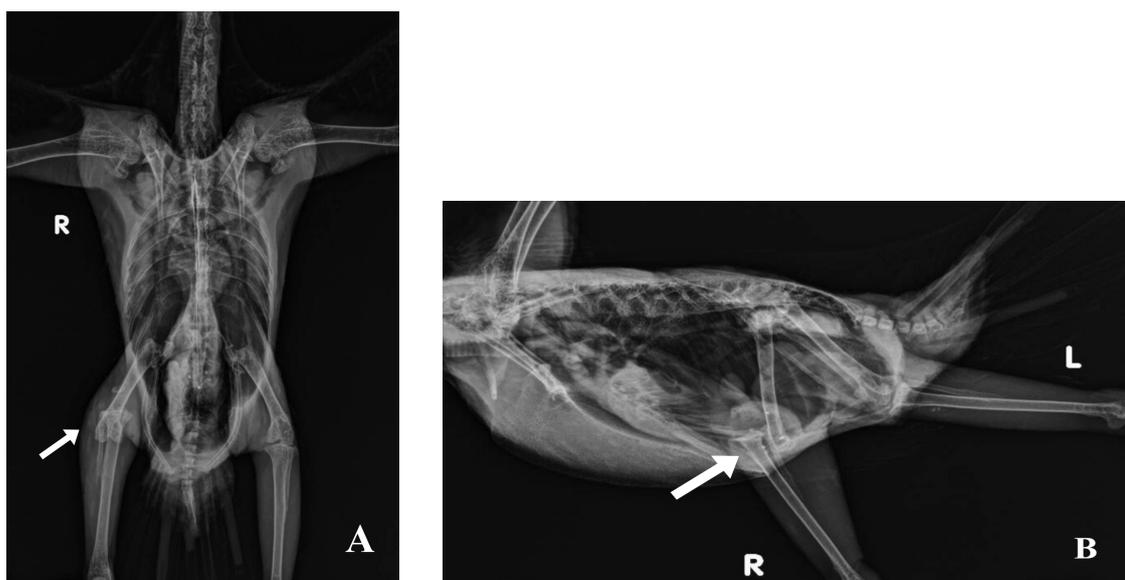


Figure 2. Radiographs depicting craniocaudal (A) and mediolateral (B) views reveal laxation of the right femorotibial joint (white arrow). The mediolateral view showed complete right femorotibial joint dislocation with cranioproximal luxation of the tibiotarsus with no associated fracture, accompanied by soft tissue swelling.

Table 1. The pre-operative blood profile included white blood cell counts and serum biochemistry results.

White blood cell counts		
Parameter	Result	Reference range*
Band heterophil	0	0 %
Segmented heterophil	85	50-75 %
Lymphocyte	12	23-53 %
Monocyte	3	0-1 %
Eosinophil	0	0 %
Basophil	0	0-1 %
Blood chemistry		
Parameter	Result	Reference range**
AST	1733	105-324 U/L
BA	< 35	7-60 umol/L
CK	5074	101-300 U/L
UA	5.0	2.9-10.6 mg/dL
GLU	2477	225-330 mg/dL
CA	10.5	8.2-10.9 mg/dL
PHOS	5.4	2.0-12.0 mg/dL
TP	4.2	2.6-5.0 g/dL
ALB	2.5	1.1-2.5 g/dL
GLOB	1.7	0.8-1.9 g/dL
K ⁺	6.1	2.0-5.0 mmol/L
NA ⁺	157	140-165 mmol/L

Note: *Reference ranges for white blood cell counts from the exotic animal formulary, 5th edition; **Reference ranges of serum parameters analyzed by VETSCAN VS2 Chemistry Analyzer.

Abbreviations: AST, Aspartate aminotransferase; BA, Bile acid; CK, Creatine Kinase; UA, Uric acid; GLU, Glucose; CA, Calcium; PHOS, Phosphorus; TP, Total protein; ALB, Albumin; GLOB, Globulin; K⁺, Potassium; NA⁺, Sodium.

Initial management attempt

The bird had a normal appetite and vocalization, but activity levels decreased due to difficulty bearing weight on one limb. Evaluating the bird's degree of lameness assessment using a standardized scale ranging from 0 to 5 (Table 2) (Anderson et al., 2002), evaluating pain at preoperative, postoperative, and post-fixator removal

time points. In this case, the bird was assigned a grade of 5 before surgical intervention.

An initial closed reduction attempt under sedation failed to maintain joint stability, leading to a decision for surgical intervention using a FESSA hinged linear transarticular external fixator (HLTEF).

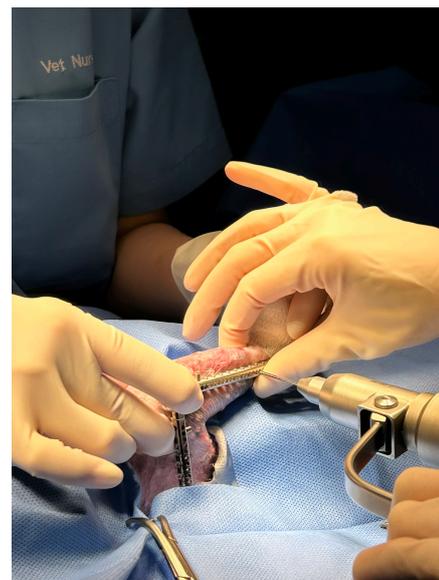
Table 2. Modified lameness grading (Anderson et al., 2002).

Score	Degree of lameness
0	Normal leg or wing function
1	Subtle, intermittent weight-bearing lameness or wing droop
2	Subtle, consistent weight-bearing lameness or wing droop
3	Obvious weight-bearing lameness or wing droop
4	Intermittent non-weight bearing lameness or wing droop
5	Consistent non-weight bearing lameness or wing droop

Anesthesia and surgical procedure

Midazolam, butorphanol, and ketamine were administered as a singular intramuscular injection. Midazolam was administered intramuscularly at a dosage of 3 mg/kg (Carpenter and Marion 2018) for sedation and anxiolysis. Additionally, butorphanol was administered intramuscularly at a dosage of 0.2 mg/kg for analgesia (Carpenter and Marion 2018). Ketamine was also administered intramuscularly at a dosage of 5 mg/kg to induce anesthesia (Carpenter and Marion 2018). Isoflurane was administered via a size No. 5 endotracheal tube to sustain the anesthetic state.

The dislocated joint was manually reduced in a sterile manner prior to stabilization with a hinged transarticular external fixator while the patient was positioned in dorsal recumbency (Figure 3). A hinge was connected to two FESSA tubes controlling flexion at 70° and two 75 mm FESSA fixators compatible with 8 mm hinges and screws. A pin was inserted into the tibiotarsus, with the hinge aligned at the same elevation as the femorotibial joint. The initial 1.5 mm stainless steel pin was inserted distally into the tibiotarsus (Figure 4). Subsequently, a second pin was inserted proximally into the tibiotarsus. Two trans cortical pins were inserted into the femur, one proximally and one

**Figure 3.** A surgical position in dorsal recumbency.**Figure 4.** Place a pin at the distal tibiotarsus and position the hinge at 70°. The hinge was positioned at the same level as the femorotibial joint.

distally (Figure 5). All pins were interconnected through a FESSA tube system equipped with a unidirectional hinge, secured with screws, to ensure controlled joint stability and mobility.

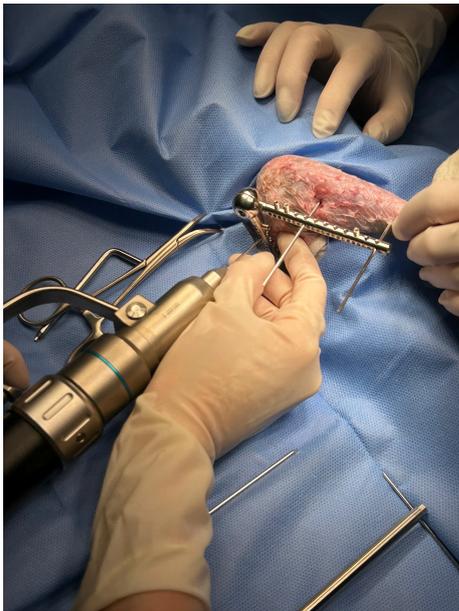


Figure 5. Proceeding with femoral pin insertion.

Post-operative verification

Radiographic verification of the proximal femur pin should be acquired (Figure 6) to confirm that the pin insertion depth is adequate prior to performing the pin cut and to confirm proper bone alignment (Figure 7).

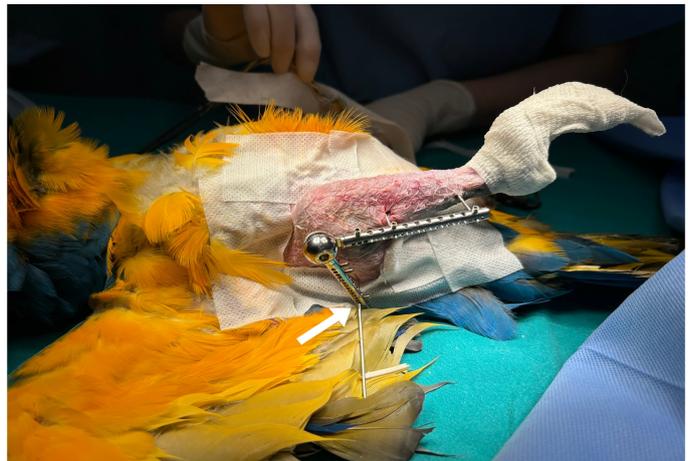


Figure 6. The proximal femur pin (white arrow) should be placed to ensure that the pin insertion depth is appropriate prior to executing the cut on the pin.

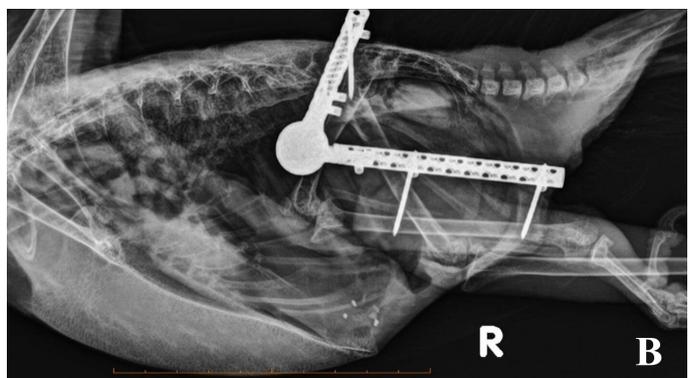


Figure 7. Postoperative craniocaudal (A) and mediolateral view (B) radiographs showing the realignment of the right femorotibial joint after hinged external fixation.

Postoperative care/outcome

A ceftiofur crystalline free acid (Excede®, Zoetis) dose of 50 mg/kg was administered intramuscularly every 4 days for infection control. This treatment was continued for two injections. For pain control, a robenacoxib dose of 10 mg/kg was administered intramuscularly every week.

Postoperative care involved placing the bird in a restricted enclosure with perches in cage rest, and a collar was applied to prevent biting at the external fixation site (Figure 8). The postoperative management plan included limiting the bird to cage rest with a perch. Magnetotherapy, which is a non-invasive alternative medicine technique that uses magnetic fields, was administered twice daily for one week to reduce soft tissue inflammation and pain, and weekly wound examinations were conducted. One week postoperatively, the bird displayed a normal appetite and



Figure 8. Postoperatively, the bird was placed in a restricted enclosure with a perch for cage rest and was fitted with a collar.

was able to grasp the perch in a typical position; however, it exhibited subtle and intermittent weight-bearing lameness, which was assessed as grade 1 on the lameness scale. There was no evidence of inflammation at the wound and no pin site infection (Figure 9). By the second week, the macaw was partially weight-bearing, stable in perching, and had a lameness score of 1. At the follow-up three weeks after surgery, the external fixator was removed in the third week (Figure 10), the lameness score remained at 0, indicating complete recovery. Subsequently, the bird regained full limb function with no recurrence of femorotibial luxation. Postoperatively at six months, the bird demonstrated the ability to grasp fruit and perch in a normal position, indicating functional recovery and a favorable outcome (Figure 11).



Figure 9. One week postoperatively, the bird was able to grasp the perch in a normal position.

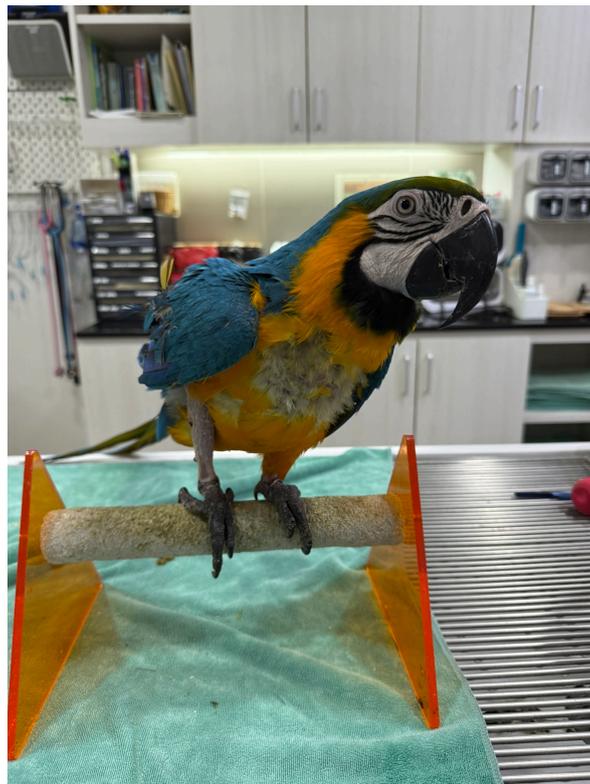


Figure 10. Three weeks postoperatively, the bird was able to grasp the perch in a normal position after the removal of the external fixation.



Figure 11. Six months postoperatively, the bird demonstrated the ability to grasp fruit (A) and perch in a normal position (B), indicating functional recovery.

Discussion

Luxation of the femorotibial joint in birds generally results from trauma (Bowles and Zantop 2002). There is limited clinical experience with the surgical management of luxation or dislocations of the femorotibial joint (Orosz et al., 2023). The luxation occurs craniolaterally, craniomedially, caudolaterally, and caudomedially with concomitant damage to the collateral and cruciate ligaments, while meniscal damage is rarely diagnosed (Azmanis et al., 2014).

The FESSA system was initially developed for complex fractures in human medicine and has been successfully adapted for use in veterinary practices, particularly in small animals like dogs, cats, and rabbits (Hatt et al., 2007). Hinge can be connected to two FESSA tubes, resulting in a FESSA hinged linear transarticular external fixator (Azmanis et al., 2006).

Immobilization of the legs aims to achieve periarticular fibrosis and stabilize the femorotibial joint (Luparello et al., 2011). Periarticular fibrosis may develop within three days following injury, potentially impeding complete recovery from the luxation and increasing the risk of joint ankylosis (Azmanis et al., 2011). In addition, it is crucial to employ precise surgical techniques to prevent permanent ligamentous laxity resulting from improper anatomical repositioning or inadequate relaxation of surrounding tissues (Azmanis et al., 2011). Surgical intervention as soon as possible after injury is crucial to optimize the prognosis and ensure favorable outcomes.

The normal standing angle for avian species remains critical in surgical recovery. Perching-joint angles varied between birds of the same species. Thus, the radiographic perching-joint angles observed in our study are guidelines to approximate joint angles before surgery (Bonin et al., 2007). In another study, the femorotibial angle was evaluated in the healthy male eclectus parrot, resulting in a measured angle

of 60 degrees from lateral standing radiographs (Harris et al., 2007). Although in the blue-and-gold macaw there was no standardized reference for the normal femorotibial joint angle. In this study, it was feasible to approximate this angle based on the proportional dimensions of a normal limb.

Several surgical techniques are available for correcting femorotibial joint luxation, depending on the severity of the injury, patient size, and different complications. Relevant studies include one that found conjoined intramedullary pin placement in a Solomon Island eclectus parrot increased the risk of trauma and osteoarthritis (Harris et al., 2007).

Furthermore, a documented case involved a 3-month-old umbrella cockatoo (*Cacatua alba*) with a right medial femorotibiotarsal subluxation, using a modified lateral extracapsular suture technique, incorporating a self-tapping cortical screw in the lateral femoral condyle and a hole through the proximal tibiotarsus (McRee et al., 2017). Radiographic evaluations 209 days postoperatively revealed severe osteoarthrosis of the femorotibial joint and persistent implant migration. After removing the screw, however, ankylosis had already developed at a physiologic perching angle (McRee et al., 2017). In this case, an essential aspect of transarticular external skeletal fixation alone is to avoid penetrating the joint to minimize the risk of osteoarthritis. The joint should remain unopened, and the reduction should be maintained to prevent the development of osteoarthritis and ankylosis.

However, using hinged transarticular external fixation in small birds is a limitation. The small size of these birds makes the placement of the fixation device challenging, which may lead to additional trauma. Additionally, the weight of the fixation apparatus may be excessive. Therefore, the size of the birds affects the surgical procedures.

Establishing the appropriate joint angle was crucial, as improper fixation in an overextended or overflexed position can impair normal limb function, alter biomechanics, and increase the risk of complications such as pododermatitis (McRee et al., 2007). Other complications include pin site infection, muscle contraction, and muscle atrophy. Moreover, the role of the tibial and fibular nerves in femorotibial joint injuries can lead to temporary or permanent dysfunction, affecting mobility and perching ability (Chinnadurai et al., 2009). Stabilizing a reduced femorotibial joint luxation with a transarticular external skeletal fixation at a normal perching angle until periarticular fibrosis occurs can result in a more enhanced restoration of limb usage than external coaptation alone (McRee et al., 2017). In this case, we did not observe pododermatitis, any pin site infections, or signs of nerve damage. Limitations of this case report include a singular case, the absence of histological assessment of the joint or ligaments, and a brief follow-up period despite a 6-month evaluation.

In conclusion, this case demonstrates that hinged external fixation can provide joint stability and functional recovery in large psittacine birds, with minimal complications, suggesting it is a promising alternative to more invasive or immobilizing surgical techniques. Further research should focus on refining these interventions, determining the normal standing angle for avian species, assessing long-term joint mobility after hinged fixation in different avian species, and expanding our understanding of orthopedic care in avian species to enhance outcomes significantly.

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Nutritive Value and In-Vitro Digestibility of Blended Ratios of Wheat Offal and Wet Sorghum Brewer Residue as Feed for Livestock

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Abstract

The use of agro-industrial by-products as animal feeds has been a matter of interest for the last few decades. Hence, this study evaluated the chemical composition, volatile fatty acid profile, and in-vitro digestibility of blended ratios of wheat offal and wet sorghum brewer residue. Fresh wet sorghum brewer residue (WSBR) was collected from local gin (Burukutu) producers and blended with wheat offal (WO) on a weight-for-weight basis in the following ratios: 1WO:1WSBR, 1WO:1.5WSBR, 1WO:1.2WSBR, 1WO:2.5WSB, 1WO:1.3WSBR, and 1WO:3.5WSBR, arranged in a Completely Randomized Design. The blends were air-dried for 3 days at 39 °C. Samples of blended ratios were analyzed for chemical composition, volatile fatty acids profile, and in-vitro digestibility using standard procedures. The dry matter contents of ratios 1:1, 1:2, 1:2.5, 1:3, and 1:3.5 were significantly higher ($p < 0.05$) than the 1:1.5 ratio. The crude fibre content significantly increased ($p < 0.05$) as the proportion of WSBR increased in the blends. The carbohydrate fractions of ratios 1:2, 1:2.5, and 1:3 were significantly higher ($p < 0.05$) than those of ratios 1:1 and 1:1.5. The neutral detergent fibre was significantly higher ($p < 0.05$) in ratio 1:3.5 than in other blended ratios. Furthermore, the hemicellulose content was significantly higher ($p < 0.05$) in ratios 1:1.5, 1:2.5, and 1:3 than in ratio 1:1, and was lowest in 1:3.5. However, ratios 1:1 and 1:1.5 had significantly higher ($p < 0.05$) acetic, propionic, butyric, valeric, and lactic acid contents than the other ratios. Notably gas production was significantly highest ($p < 0.05$) in ratio 1:1 from 3 to 24 hours of in-vitro digestibility compared to other ratios. It could be concluded that blended ratios of wheat offal and wet sorghum brewer residue improved nutrient availability for livestock animals; however, ratios 1:1 and 1:1.5 produced more in-vitro gases, while ratios 1:1, 1:1.5, and 1:2 showed superior dry matter digestibility.

Keywords: Nutritive value, In-vitro digestibility, Fatty acids, Wheat offal, Wet brewer residue

Introduction

Agricultural by-products are good alternative feed for ruminants and are reported to be economical, viable, and environmental concerns (Rahman et al., 2013). These by-products can have different applications or uses. One valuable possibility in the field of animal nutrition is the recycling of these materials as alternative feedstuffs, in particular for herbivores (Salami et al., 2019). The use of agro-industrial by-products as animal feeds has been a matter of interest for the last few decades according to Vasta et al. (2008). By-products with high energy content could replace grains in the ration (Abo-Zeid et al., 2017), whereas those with high fibre content might replace roughage (Salman et al., 2014). Brewer's grains are a highly variable by-product, whose composition and nutritional value depend on the grain used, the industrial process (e.g., temperature, fermentation), and the method of preservation. Brewer's grains are sold wet or dried, and can be ensiled (Blezinger 2003). Wet brewery waste is a typical example of alternative feed, being used in diets for ruminants due to its high nutritional content, especially energy and protein, and great availability along the year for a low cost, which may minimize the costs of animal feeding (Souza et al., 2012). However, the wet brewery waste presents a low dry matter content (ranging from 9 to 30%), which represents an expressive limiting factor for its effective use, causing problems for transport, storage, and preservation of this by-product (Geron et al., 2007). The high moisture content and storage conditions of the wet brewery waste under aerobic environment, commonly used on farms, provide ideal conditions for the development of microorganisms, mainly filamentous fungi (Souza et al., 2012). These fungi promote the degradation of the waste' nutrients and can produce toxins that affect animal metabolism. Difficulty in the conversion of high-moisture by-products arises from high cost of drying equipment and lack of simple and appropriate alternatives (Makinde and Sonaiya 2010). Makinde and Sonaiya (2007) developed a quick method (maximum of 4-h drying period) to convert such wet sorghum brewer residue using vegetable carriers (wheat offal) as absorbents.

The wheat offal prevents nutrient seepage while enhancing drying. Therefore, this study aimed to determine the nutritive value and in-vitro digestibility of blended ratios of wheat offal and wet sorghum brewer's residue.

Materials and methods

Experimental location

This study was conducted at the Department of Animal Health and Production Technology, The Oke Ogun Polytechnic, Saki Teaching and Research farm, located at longitude 8.6275°N and latitude 3.4058°E in Oyo State, Nigeria.

Processing of wheat offal and sorghum brewer wet waste blended ratios

Wheat offal (WO) was purchased from a reputable feed mill while fresh wet sorghum brewer residue (WSBR) was collected in polyethylene woven sacks from local gin (Burukutu) producers in Ago Are at ATISBO Local Government Area of Oyo State, Nigeria. The blended ratios were mixed weight for weight: 1WO:1WSBR, 1WO:1.5WSBR, 1WO:1.2WSBR, 1WO: 2.5WSBR, 1WO:1.3WSBR, and 1WO:3.5WSBR. The mixtures were air-dried by spreading thinly on black polythene sheets (0.7 mm thickness) in two replicates each on the concrete floor for 3 days at room temperature (39 °C). The dried blends were stored in high-density polythene bags and then kept in a cool dried place.

Chemical analysis

Samples of WSBR and blended ratios were analyzed for chemical composition (dry matter (DM), ash, crude protein, starch, neutral detergent fibre (NDF), and acid detergent fibre (ADF) following previously described methods. Specifically, feedstuff samples were oven-dried at 100 °C for DM (988.05) and for ash content by combustion at 600 °C (942.05) (AOAC 2012). Kjeldahl method (AOAC 2012) was used for N analysis and CP was determined based on N x 6.25. Furthermore, NDF and ADF were determined based on Mertens (2002). Oil

content was determined by the "Wiebul" acid hydrolysis method and ether extract (EE) content was measured by direct solvent extraction (Soxhlet 1879). Metabolizable energy (ME, MJ/kg DM) content was estimated using CP and EE contents (in g/kg DM) and the volume of gas measured after 24 h of incubation (G24 in mL per 200 mg DM incubated) as described by Menke and Steingass (1988):

$$ME = 2.43 + 0.1206 \times G24 + 0.0069 \times CP + 0.0187 \times EE$$

The carbohydrate was determined using the formula (DM basis) = 100 - (CP + EE + Ash + CF) while the Hemicellulose = NDF - ADF and Cellulose = ADF - ADL were estimated.

Determination of in-vitro gas production

Ruminal fermentation of the blended ratio samples was conducted using an in-vitro gas production technique described by Menke and Steingass (1988), as demonstrated previously by Santoso et al. (2019). Briefly, 300 ± 5 mg of the oven-dried samples were put into 100 mL glass syringes (3 replications per sample) (Model Fortune, Häberle Labortechnik, Germany). Syringes were filled with 30 ± 1.0 mL of rumen fluid-buffer mixture and placed in a water bath at 39 °C for 48 hours. Each syringe was then gently shaken by hand every 8 hours. The gas production from each syringe was recorded before incubation (0 h) and after 3, 6, 9, 12, 15, 18, 21, and 24 hours of incubation. The gas production was blank-corrected, adjusted to standard temperature and pressure (STP), and expressed per unit of substrate (e.g., mL/200 mg DM). The sample of about 10 mL of the syringe content was drawn at the end of the incubation period. The pH of the medium was immediately measured using a digital pH meter (Hanna, Hi 8520, Ronchi di Villafranca, Italy). Two milliliters of sub-sample were added to 2 mL of 20 g/L (w/v) NaCl for NH₃-N analysis. The in-vitro dry matter digestibility (IVDMD) was done using the formula of Tilley and Terry (1963):

$$IVDMD (\%) = \frac{M - (U - B)}{M} \times 100$$

Where: M is the weight of dry matter incubated (g), U is the weight of undigested dry residue after incubation (g), and B is the mean dry matter residue from the blank (g).

Determination of volatile fatty acids

Volatile fatty acids (VFAs) in the blended ratio samples were determined following the procedures of Erwin et al. (1961) and Playne (1985), with slight modifications. Approximately 2.0 g of fresh or ground feed was weighed into a 50 mL centrifuge tube and mixed with 10 mL of distilled water containing an internal standard (2-ethylbutyric acid). The mixture was homogenized, centrifuged at 4,000 x g for 10 min at 4 °C, and the supernatant was transferred to a clean tube. To stabilize VFAs and precipitate proteins, 25% metaphosphoric acid was added at a ratio of 1:4 (v/v, acid:extract) to achieve a final concentration of 5%. The mixture was incubated on ice for 20 min, centrifuged at 10,000 x g for 10 min, and the clear supernatant was filtered through a 0.45 µm syringe filter into gas chromatography (GC) vials. VFA concentrations were quantified using a gas chromatograph (equipped with a flame ionization detector and a Nukol capillary column, 30 m x 0.25 mm x 0.25 µm). The injector and detector were maintained at 250 °C, and helium was used as the carrier gas at a flow rate of 1 mL/min. The oven program started at 60 °C (2 min), increased by 10 °C/min to 150 °C, and was held for 5 min. One microlitre of each sample was injected, and VFAs were identified by comparing retention times with those of external standards (acetate, propionate, butyrate, iso-butyrate, valerate, iso-valerate, and caproate). Concentrations were calculated using calibration curves constructed from VFA standards, and results were expressed as grams per kilogram of feed dry matter.

CH₄ production estimates

Before sample injection, a five-point (25,000, 50,000, 75,000, and 100,000 ppm) standard curve for CH₄ was created to allow calculation of CH₄ concentrations of samples using peak area. Following the gas pressure readings and for each reading time point, a sample (10 mL) of gas was collected from each flask using a two-way valve on the pressure transducer and was manually injected into a gas chromatograph (Bruker 450 GC) via the port valve to

determine the CH₄ concentration. Full column and GC conditions were previously reported (Munoz et al., 2012). Gas components were separated on a CH₄-packed Poropak N column (1.2 m length, 2 mm i.d. Varian Inc., Walnut Creek, CA), and CH₄ was detected using a flame ionization detector. The CH₄ concentrations were applied to calculated gas volumes to obtain CH₄ volume. For each reading time point, the CH₄ volumes were expressed as cumulative CH₄ yield was measured in mL/g substrate. Similar to the gas dataset, cumulative CH₄ yield curve profiles were fitted based on the model described by France (1993).

Data analysis

The data collected were subjected to a one-way analysis of variance procedure of the General Linear Model of SAS (2002) version 9.0. Significant means ($p < 0.05$) were separated using the Duncan New Multiple Range Test. The following statistical model was applied to the data analysis:

$$Y_{ij} = \mu + F_i + E_{ij}$$

Where: Y_{ij} = all independent variables, μ = overall mean, F_i = effect of blended ratios, and E_{ij} = random error.

Results

Chemical composition of WO:WSBR blended ratios

The values for the chemical components of wet sorghum brewer residue were far lower than the various blended ratios (Table 1). There were significant differences ($p < 0.05$) among all chemical components across the blended ratios except for crude protein, metabolizable energy, and cellulose contents. The dry matter contents of ratios 1:1, 1:2, 1:2.5, 1:3, and 1:3.5 were significantly ($p < 0.05$) higher than 1:1.5 ratio. The crude fibre content significantly increased ($p < 0.05$) as the blended ratios increased. The carbohydrate fractions of 1:2, 1:2.5, and 1:3 were significantly higher ($p < 0.05$) than that of ratios 1:1 and 1:1.5. The neutral detergent fibre was significantly higher ($p < 0.05$) in ratio 1:3.5 than other blended ratios.

However, there were no significant differences ($p > 0.05$) among the gross energy and cellulose contents of the blended ratios. The ratio 1:3.5 had significantly higher ($p < 0.05$) neutral detergent fibre, acid detergent fibre, and acid detergent lignin than the other blended ratios. However, ratios 1:1.5, 1:2.5, and 1:3 had significantly higher ($p < 0.05$) hemicellulose than 1:1 and 1:3.5 the least.

Volatile fatty acids content of WO:WSBR blended ratios

There were no significant ($p > 0.05$) differences in the pH and ammonia contents of the blended ratios (Table 2). However, ratios 1:1 and 1:1.5 had significantly higher ($p < 0.05$) acetic, propionic, butyric, valeric, and lactic acid contents than other ratios. Most volatile fatty acids values decreased with increasing blended ratios. Conspicuously, the total volatile fatty acid content was significantly highest ($p < 0.05$) in ratio 1:1 followed by 1:1.5, 1:2.5, 1:2, 1:3, and lowest in 1:3.5.

In-vitro gas production and digestibility of WO:WSBR blended ratios

There was no significant difference ($p > 0.05$) in gas production at 3 hours across the blended ratios (Table 3). Conspicuously, the gas production was significantly highest ($p < 0.05$) ratio 1:1 from 6 to 24 hours of in-vitro digestibility compared to other ratios. Furthermore, the methane and carbon dioxide gas produced were significantly ($p < 0.05$) higher in ratio 1:1 than other ratios. The in-vitro dry matter digestibility was significantly highest ($p < 0.05$) in ratios 1:2 and 1:1 followed by 1:3, 1:1.5, 1:3.5, and lowest in 1:2.5.

Table 1. Chemical composition of wheat offal and wet sorghum brewers waste blended ratios.

Parameters (%)	Blended ratios							SEM
	WSBR	1:1	1:1.5	1:2	1:2.5	1:3	1:3.5	
Dry matter	42.76	97.11 ^a	91.66 ^b	96.94 ^a	97.05 ^a	98.26 ^a	98.20 ^a	0.70
Crude protein	0.49	2.72	2.52	2.59	2.88	2.52	3.21	0.11
Crude fibre	17.34	13.84 ^d	14.98 ^c	14.75 ^c	16.21 ^b	15.86 ^b	19.57 ^a	0.49
Ether extract	2.62	8.77 ^b	9.66 ^b	9.77 ^b	9.99 ^b	9.53 ^b	10.19 ^a	0.21
Ash	1.41	16.38 ^a	8.06 ^b	8.11 ^b	7.62 ^b	8.59 ^b	8.61 ^b	0.92
Carbohydrate	20.90	51.72 ^c	51.08 ^c	61.96 ^a	61.12 ^a	61.09 ^a	57.13 ^b	1.36
ME (KJ/kg)	1050.00	2907.50	2886.00	2860.00	2835.50	2821.00	2892.50	18.49
NDF	22.19	36.10 ^{ab}	34.88 ^b	36.83 ^{ab}	36.21 ^{ab}	35.76 ^{ab}	37.24 ^a	0.78
ADF	14.34	21.28 ^c	17.81 ^d	23.72 ^b	20.84 ^c	18.38 ^d	24.21 ^a	0.67
ADL	9.23	12.65 ^b	11.56 ^c	13.87 ^{ab}	11.93 ^c	10.22 ^d	15.28 ^a	0.41
Hemicellulose	7.85	13.67 ^b	16.56 ^a	13.09 ^b	15.65 ^a	16.34 ^a	12.71 ^c	0.31
Cellulose	5.11	9.53	7.80	10.47	8.47	7.78	9.12	0.16

Superscript letters (^{a-d}) indicate that values with different superscripts are significantly different ($p < 0.05$).

Note: ME is metabolizable energy, NDF is neutral detergent fibre, ADF is acid detergent fibre, and ADL is acid detergent lignin.

Table 2. Volatile fatty acid profile of wheat offal and wet sorghum brewers waste blended ratios.

Parameters (%)	Blended ratios						p-value	SEM
	1:1	1:1.5	1:2	1:2.5	1:3	1:3.5		
Acetic acid	30.90 ^a	28.93 ^a	15.12 ^{bc}	19.20 ^b	15.65 ^{bc}	12.12 ^c	0.0005	0.22
Propionic acid	31.36 ^a	27.73 ^a	14.69 ^{bc}	18.54 ^b	14.41 ^{bc}	12.43 ^c	0.0002	0.21
Butyric acid	2.43 ^a	2.31 ^a	1.49 ^b	1.46 ^b	1.43 ^b	1.19 ^b	0.0025	0.17
Valeric acid	27.07 ^a	23.47 ^b	14.46 ^d	17.35 ^c	13.75 ^d	12.14 ^d	<0.0001	0.18
Lactic acid	32.17 ^a	28.30 ^a	17.78 ^b	22.69 ^{ab}	18.6 ^{ab}	16.37 ^b	0.0545	0.21
TVFA	45.22 ^a	36.55 ^b	25.01 ^d	27.89 ^c	21.39 ^e	19.39 ^f	0.0002	2.76
pH	5.60	5.60	5.	5.65	5.45	5.10	0.3012	0.08
NH ₃	0.38	0.30	0.35	0.28	0.28	0.28	0.4608	0.02

Superscript letters (^{a-f}) indicate that values with different superscripts are significantly different ($p < 0.05$).

Note: TVFA, Total volatile fatty acids.

Table 3. In-vitro gas production and digestibility of wheat offal and wet sorghum brewers waste blended ratios.

Parameters (%)	Blended ratios						p-value	SEM
	1:1	1:1.5	1:2	1:2.5	1:3	1:3.5		
3 hours	2.33	1.33	1.00	2.33	1.00	2.33	0.0898	0.21
6 hours	4.33 ^a	3.67 ^b	2.33 ^c	4.00 ^{ab}	2.67 ^{bc}	4.00 ^{ab}	0.1206	0.26
9 hours	6.67 ^a	5.67 ^{ab}	4.67 ^b	6.33 ^a	4.67 ^b	6.00 ^a	0.1206	0.26
12 hours	9.67 ^a	7.67 ^{bc}	6.67 ^c	8.33 ^b	6.67 ^c	8.00 ^b	0.0011	0.28
15 hours	13.00 ^a	10.00 ^b	7.67 ^d	10.67 ^b	8.67 ^c	10.00 ^b	0.0006	0.45
18 hours	16.00 ^a	12.33 ^b	8.33 ^d	13.00 ^b	10.33 ^c	12.00 ^b	<0.0001	0.59
21 hours	18.00 ^a	14.67 ^b	9.33 ^e	14.67 ^b	11.33 ^d	13.33 ^c	<0.0001	0.68
24 hours	20.33 ^a	17.33 ^b	9.67 ^f	15.33 ^c	11.67 ^e	13.67 ^d	<0.0001	0.87
Methane	4.33 ^a	4.00 ^a	2.00 ^c	4.00 ^a	3.00 ^b	3.00 ^b	0.0308	0.63
Carbondioxide	9.00 ^a	7.67 ^b	4.67 ^d	6.33 ^c	5.00 ^d	6.00 ^c	0.0344	1.19
DM Digestibility (%)	56.77 ^a	51.12 ^b	58.67 ^a	43.67 ^d	53.70 ^b	51.52 ^c	<0.0001	1.92

Superscript letters (^{a-f}) indicate that values with different superscripts are significantly different ($p < 0.05$).

Note: DM, Dry matter

Discussion

Chemical composition of WSBR and WO:WSBR blended ratios

The proximate components of WSBR in this study were lower than 70% moisture, 3% crude protein, 1% ether extract, and 2% ash, but within the range of 4-40% crude fibre content reported for wet brewers spent grains (Musatto et al., 2006). Furthermore, the fibre fractions of WSBR were far lower than 60% neutral detergent fibre, 30% acid detergent fibre, and 20% hemicellulose, but within the range of 8-20% acid detergent lignin for spent brewer grains revealed by Aliyu and Bala (2011). These differences in nutritional contents might be attributed to the processing methods, the type grains used, and fermentation methods adopted in these studies. Therefore, simple and quick processing to improve the utilization of WSBR is inevitable. The moisture content in this study was less than 12% desirable pertaining to good keeping quality of feedstuffs (Rozis 1997). The crude protein concentrations of the blended ratios were far lower than the recommended value of 7-8% for ruminants to have active and healthy rumen environment (McDonald et al., 2002). Hence these products are not suitable as protein source for poultry, rabbits, and pigs. The crude fibre in this study was higher than 7.61-10.00 reported by Makinde et al. (2011) for

blended ration of pineapple wastes and wheat offal but lower than 24.70 reported for rice bran by Ogunbosoye and Salau (2020). The crude fibre content of blended products is in agreement with less than 18% recommended for sheep and goat maintenance diet (NRC 2007), 18-20% required for breeding or adult beef cow (NASEM 2016), and 15-19% for dairy cattle to prevent rumen acidosis and maintain milk fat (NRC 2001). The crude fibre of all the blended ratios were higher than 7% recommended for poultry birds by NRC (1994), slightly higher than 8-12% for sow (NRC 2012), but blended ratios 1:1, 1:1.5, 1:2, and 1:3 were suitable for feeding rabbits (12-16%) as reported by Gidenne (2015). It is then evident that these are suitable blended products. The carbohydrate fraction was slightly lower than 59.17-65.66 revealed by Olosunde et al. (2023) for recycled cashew pulp as animal feed. Furthermore, the carbohydrate fraction in this study was higher than 25-40 for brewer spent grain (Musatto et al., 2006) and 30-38 for rice bran (Saunders 1990), within 60-70 for wheat bran (Mateos et al., 2019), but slightly lower than 66.56 for cassava peel (Amaza 2021) and 70.50 for molasses (Shafiq-Arikah et al., 2022). Therefore, all WSBR blended ratios were suitable as carbohydrate sources for livestock animals. The NDF values in this study were lower than 72.62-81.86 for maize fodder (Ayandiran et al., 2024)

while the ADF was lower than 46.45 reported for corn bran (Ogunbosoye and Salau 2020). The NDF and ADF in this study were in agreement with recommended ranges for ruminant animals by NRC (2016 for cattle and 2007 for sheep and goats). The hemicellulose content in this study was slightly lower than 17.24-28.59 for agro-industrial by-products, but within 13.96-19.51 for grains reported by Kumar et al. (2015). Moderate fibre fractions in monogastric animal diets improve guts health and motility, microbial fermentation in the hindguts as well as increase satiety and feed intake control, however, excessive fibre in feed reduces feed intake, depresses nutrient digestibility, and energy utilization (NRC 2011; NRC 2012; Gidenne 2015). Furthermore, optimal fibre fraction in ruminant's diets maintains rumen health, provides energy through fermentation, and enhances feed intake and nutrient digestibility while excessive fibre increases methane production and causes nutrient imbalance (Van Soest 1994). Hence these blended products are suitable for feeding ruminant animals especially during the dry season when forages are scarce and even limited in essential nutrients.

Volatile fatty acids content of WO:WSBR blended ratios

The volatile fatty acids profile varied significantly among the blended ratio reflecting differences in their chemical composition and fermentation characteristics attributed to varying carbohydrates composition and structures (Marcos et al., 2020). Variables such as volatile fatty acids, pH value, and NH_3 concentration are commonly used as criteria to assess the quality of fermentation (Santos et al., 2020). Acetic acid is produced from fibre fermentation and enhances milk fat content in dairy animals. The acetic acid in this study was far lower than 70.2-75.0 by Christodoulou et al. (2025) for agro-industrial protein-rich products. Danner et al. (2003) reported that lactic acid was more effective in lowering fermentation pH than other volatile fatty acids. The lactic acid in this study was lower than 68.9-90.5% reported by Santos et al. (2020) as well as 80-120% by Chamberlain and Wilkinson (1996). Butyric acid concentrations are important indicator in determining the

fermentation quality (Santos et al., 2020). The butyric acid content in this study is slightly higher than 12.2-14.50 reported by (Hassan et al., 2025). Propionic production indicates improved fermentation efficiency as propionate acts as a hydrogen sink, potentially reducing methanogenesis (Van Soest 1994). The propionic acid in this study was in agreement with the 18.4-21.7 reported by Hassan et al. (2025) for agro wastes. It is noteworthy that all blended product in this study produced enough volatile fatty acids for production and maintenance functions of all categories of livestock animals.

In-vitro gas production and digestibility of WO:WSBR blended ratios

The measurement of in-vitro gas production is a good indicator used to predict rumen degradability efficiency and metabolizable energy of animal feed (Contreras-Govea et al., 2011). The increase in in-vitro dry matter digestibility and in-vitro organic matter digestibility with increasing protein levels indicates the potential for improving feed efficiency of low-quality forages (Bargo et al., 2003). The result was consistent with the report of Pereira et al. (2013) where some agro-industrial by-products were evaluated in vitro. The 24 hours gas production was lower than 32.67-40.35 reported by Ayandiran et al. (2024) for ensiled Elephant grass. The reduction in the gas produced when the ratio of WSBR increased could be attributed to high ADF and ADL forming complexes with cellulose and hemicellulose (Getachew et al., 2002). The presence of secondary metabolites such as tannins, saponins, alkaloids, and phenolic compounds, which bind proteins and carbohydrates, inhibits microbial enzymes, or are toxic to rumen microbes, can lower gas production (Makkar et al., 1995). The volume of methane produced in this study was lower than 5.50 for corn bran (Ogunbosoye and Salau 2020) but similar to the value of Kim et al. (2013) who compared with wheat bran and palm kernel. Methane production is of no use to ruminants but represents a big waste of energy and in fact, it contributes to greenhouse emission (Silivong et al., 2013), for which its

production to the atmosphere should be reduced. The digestibility in this study was comparable with 47.67-61.41 reported by Ayandiran et al. (2024). The higher dry matter digestibility revealed in blended ratios 1:1 and 1:2.0 could be linked to lower ADL fractions as opined by Jung et al. (1995), who stated that lignified feeds ferment slowly, reducing rate of VFA production and energy supply to animals. Furthermore, studies consistently showed a negative correlation between lignin and in-vitro/in-vivo fibre digestibility (Jung et al., 1997).

Conclusion and recommendation

It could be concluded that blended ratios of wheat offal and wet sorghum brewer residue have improved nutrient availability for livestock animals. However, ratios 1:1 and 1:1.5 produced more in-vitro gases, while ratios 1:1, 1:1.5, and 1:2 had superior dry matter digestibility. Based on the findings from this study with respect to fibre contents, none of these blended ratios are suitable for poultry birds. Blended ratios 1:1, 1:1.5, and 1:2 might be suitable for rabbits and pigs. However, all blended ratios could be fed to ruminant animals.

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Quality Evaluation of Chicken Powder from Broiler Chicken Fed Abattoir Wastes in Their Diet

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Abstract

There is an increasing desire and demand for animal products with improved nutritional quality, resulting in the inclusion of abattoir waste in the feed of broiler chickens used as a raw material for the processing of chicken powder (CP). A total of 150 Ross breed chicks were raised intensively for 8 weeks. The birds were fed compounded feed (CF) with inclusion of abattoir waste (AW) and allocated to five dietary treatments (T) in a completely randomized design: T1, CF only; T2, CF + 5% AW; T3, CF + 10% AW; T4, CF + 15% AW, and T5, CF + 20% AW. Three chickens were selected from each treatment for CP processing. Result on day 0 showed that inclusion of AW in the diet of broiler chickens increased the protein of CP. Moisture content increased with increasing AW. Cholesterol in all treatments was below the limit recommended for broilers and their products. No significant difference ($p > 0.05$) was observed in iron (Fe), while sodium (Na) and potassium (K) increased with AW. On day 28, no significant changes were observed in protein content; however, storage intervals caused variation in ash and moisture content. T2 and T3 had the lowest microbial load on day 0 and 28. Microbial load increased with AW, and T4 and T5 were significantly ($p < 0.05$) higher in total viable count (TVC) and total bacteria count (TBC). Result for palatability showed that T2 was significantly preferred, followed by T1 and T3 with no significant difference. CP is a high-protein animal product in which the nutritive component is enhanced with inclusion of 5-10% abattoir waste in the diet of broiler chicken.

Keywords: Broiler chicken, Abattoir waste, Chicken powder, Microbial load

Introduction

Abattoir waste presents a potential alternative protein source, converting waste into a usable feed stuff and offering a cost-effective and locally available feed stuff for broiler chicken when safely selected, processed, and incorporated into the broiler chicken diet (Onunkwo et al., 2018). Sakaba et al. (2017) reported that, abattoir waste is rich in vital and required nutrients containing 5.83% moisture content, 15.52% crude protein, 5.17% lipid, 48.73% fiber, 11.00% ash, and 19.98% nitrogen free extract (NFE). The findings of Onunkwo et al. (2018) established that bovine blood and rumen content have 9.34% moisture content, 35.33% protein content, 3.60% ether extract, 15.57% crude fiber, 0.98% ash, and 25.06% NFE. The nutrient profile of abattoir waste has thus qualified it to be an alternative feed source that can be explored in poultry production. Safe incorporation of well-processed abattoir waste into feed ingredients reduces the cost of feeds, minimizes abattoir waste accumulation, improves environmental hygiene, promotes recycling, and encourages integration within the livestock farming system (Onunkwo et al., 2018). The use of abattoir waste in the diet of broiler chicken will be a financial relief for poultry farmers by reducing the exorbitant cost of feeding. Othman et al. (2017) reported that, feeding is a major challenge in poultry production, necessitating the need for the development of alternative feed stuff to ensure feed quality, sustainable production, and stable consumption of chicken meat. It was also buttressed by Fakolade et al. (2025) that abattoir wastes can be used to lower the cost of production of broiler chicken and also enhance value addition of chicken meat into other products.

Chicken meat is the most consumed type of poultry and it ranks second in consumption globally (Caffyn 2021). It is affordable, low in fat, and not subjected to religious and cultural constraints (FAO 2025). By nature, broiler chicken meat is a nutrient-dense food, rich in protein, vitamins and minerals, making it susceptible to deteriorative changes (Hailemariam et al., 2022). Adding value to chicken meat becomes crucial because of its tri-effects, which are: halting or slowing down of deteriorative changes in the final product, preventing economic loss via wastage, and increasing food options in the meat industry. The shift toward value addition can thus be attributed to the economic and health concerns of consumers as they seek ready-to-cook or ready-to-eat meat products with longer shelf life and improved flavour.

Chicken powder (CP) is a flavourful additive that can be used as a seasoning with authentic chicken stock taste in homemade meals (Tian et al., 2019; Shen et al., 2023). Most of the food industry pays attention to taste and flavour with less attention to nutrition and health; this result in a shift to natural, healthy, tasty, and flavourful additives such as CP (Tian et al., 2019). The outcome of CP outmatches that of artificial flavouring spices because it is rich in amino acids, nucleotides, and other flavouring components (Tian et al., 2019; Zheng et al., 2022). Shen et al. (2023) defined CP as a natural food ingredient rich in chicken flavour, which is made from quality broiler chicken as the raw material. Anderson et al. (2014) acknowledged CP as a cheap source of quality protein that can be added to home-prepared meals to improve the flavour and nutritional value of food especially its protein and micronutrient content.

CP is achieved by cooking, drying, and grinding chunks of chicken meat into a powdery form, and utilizing an array of spices and seasonings, which provides an arsenal against microbial load. Sulieman et al. (2023) projected that the incorporation of spices and seasonings into ground and dried chicken meat retards deterioration and helps in culinary enhancement. CP can be consumed as a snack, used in spicing or fortifying meal, thus, reducing malnutrition in humans (Golden 2009). It is also reported to serve as a source of animal protein with no restriction to its use as a meal-fortification in children's and adults' diets, combating the malnutrition challenge (Anderson et al., 2014).

CP is an affordable and sustainable protein source in both rural and urban communities (Rowe et al., 2008). Aslam et al. (2000) reported that, the nutritional quality of CP did not depreciate when it was stored for 140 days at room temperature. CP, therefore, addresses the perishability issue facing meat products in a developing country as a result of epileptic power supply or lack of preservation by refrigeration. Anderson et al. (2014) also noted that, CP can be transported to under-served areas where high quality protein is not available or is limited because of cost. Therefore, this study evaluated the quality and acceptability of chicken powder produced from broiler chicken fed abattoir waste in their diet.

Materials and methods

The experiment was conducted at the Poultry unit, Teaching and Research Farm, and Meat Science Laboratory, Osun State University, Ejigbo campus, Ejigbo.

Sample collection

Abattoir wastes were carefully collected at nearby abattoirs. Abattoirs with strict hygiene measures that prioritize proper segregation and collection were visited in Ejigbo, Osun State, Nigeria. The wastes were collected in leak-proof container and processed following the procedures of Fakolade et al. (2025).

Rumen content was collected and emptied into a clean bag, and the rumen fluid was squeezed out locally using hands to lower the moisture content and bulkiness of the rumen content. The rumen was spread on a tarpaulin and sun-dried in a well-aerated atmosphere. It was flipped often while drying to aid the drying process. The dried rumen content was milled into finely ground rumen content meal using a milling machine.

Blood was collected during the slaughtering of cattle. The blood was then placed to a drum and coagulated for 45 minutes on a burner at 100. During the coagulation process, the heating eliminated zoonotic disease pathogens such as brucellosis and tuberculosis (in case there were any). It was sieved after coagulation to eliminate any excess water. The coagulated blood was sun-dried on a clean aluminum sheet in a well-aerated environment, and it was frequently turned

for even dryness. The dried blood was crushed into finely ground blood meal with the aid of milling equipment.

Bones were sun-dried until the moisture content was successfully eliminated, at which time they were shattered with a hammer or mortar. After being crushed into small particles, they were steamed at 100 °C for more than 30 minutes. They were then dried and milled using a milling machine into fine particles.

Hoofs were soaked in water until they became spongy and could be detached from the bones, at which point they were spread out to dry in the sun. The horns were sun-cured until the horn pith was entirely dried for pounding to take place. The horns and hoofs were mixed and steam-cooked in an autoclave for seven hours at 100-112 °C (digester). The substance was then dried and finely ground.

Mixing of abattoir waste

Separately, milled abattoir waste was taken to a laboratory for determination of its chemical composition (Table 1). The milled mixture (rumen content, bone, horn, and hoofs) and unmilled (blood) abattoir wastes were then blended at a 1:1 ratio and used at various levels.

Table 1. Proximate composition of abattoir waste.

Parameters	%
Crude protein	17.88
Ash	53.00
Ether extract	5.44
Crude fibre	6.35
Moisture content	7.22
Nitrogen free extract	10.11
Total	100.00

Experimental birds and dietary treatments

A total of one hundred and fifty (150 birds) day-old Ross breeds of chicks were purchased from a reliable farm in Osun State. The chicks were raised in a deep litter housing system for 8 weeks (4 weeks for the starter phase and 4 weeks for the finisher phase) that is, from 5th of February to 30th of April, 2024. The birds were rightly vaccinated and appropriate medications were administered to prevent diseases and boost the chick immune system (Table 2). Abattoir wastes were incorporated into the feed ingredients of the broiler chicken at 0%, 5%, 10%, 15%,

and 20%. The birds were fed with starter diet in phase 1 (brooding took place at this phase) and finisher diet in phase 2 (Table 3 and Table 4). The experimental birds were randomly allocated to 5 treatments; each treatment had 3 replicates with 10 birds per replicate (summing up to 30 birds per treatment). The birds were subjected to 5 dietary treatments:

Treatment 1: Compounded feed with abattoir waste at 0%
 Treatment 2: Compounded feed with abattoir waste at 5%
 Treatment 3: Compounded feed with abattoir waste at 10%
 Treatment 4: Compounded feed with abattoir waste at 15%
 Treatment 5: Compounded feed with abattoir waste at 20%

Table 2. Vaccination and medication programme for broiler chicken.

Age of the birds	Types	Vaccination/Medication
Day 1	Vaccination	Marek (at the hatchery)
1 week	Vaccination	1 st (Gumboro vaccine)
2 weeks	Vaccination	1 st NDV (Lasota vaccine)
3 weeks	Vaccination	2 nd (Gumboro vaccine)
Day 1-3	Medication	Anti-stress, glucose
Day 4-6	Medication	Anti-biotic in water
Day 8-10	Medication	Live water
Day 10-13	Medication	Anti-coccidial in water
Day 15-17	Medication	Live water
Day 18-20	Medication	Vitamins
Day 22-24	Medication	Live water
Day 25-27	Medication	Anti-biotic in water
Day 29-33	Medication	Anti-coccidial in water
Day 34-35	Medication	Anti-coccidial in water
Day 36-37	Medication	Iodine in water
Day 37-40	Medication	Live water

Table 3. Experimental diet fed to broiler chicken (starter phase).

Ingredients	0% (T1)	5% (T2)	10% (T3)	15% (T4)	20% (T5)
Maize	58.94	58.64	59.58	60.65	60.40
Soya bean meal	16.0	16.0	16.0	12.35	9.90
Groundnut cake	14.50	15.38	10.00	8.20	6.20
Fishmeal	3.0	0	0	0	0
Abattoir waste meal	0	5	10	15	20
Wheat offal	4.06	1.48	0.92	0.3	0
Bone meal	2.7	2.7	2.7	2.7	2.7
Premix	0.25	0.25	0.25	0.25	0.25
Salt	0.25	0.25	0.25	0.25	0.25
Lysine	0.15	0.15	0.15	0.15	0.15
Methionine	0.15	0.15	0.15	0.15	0.15
ME in MJ kg ⁻¹	12.56	12.56	12.56	12.56	12.56
%CP	22.19	22.01	22.04	22.05	22.08
%CF	3.32	3.39	4.47	4.95	5.01
%Ca	1.26	1.09	1.09	1.09	1.1
%P	0.96	0.79	0.79	0.76	0.74
%Lysine	1.15	1.38	1.67	1.9	2.01
%Methionine	0.48	0.48	0.50	0.52	0.53

Table 4. Experimental diet fed to broiler chicken (finisher phase).

Ingredients	0% (T1)	5% (T2)	10% (T3)	15% (T4)	20% (T5)
Maize	61.42	62.47	63.75	64.37	60.75
Soya bean meal	15.80	9.80	7.20	4.25	4.01
Groundnut cake	7.00	7.80	4.50	2.85	2.21
Fishmeal	0	0	0	0	0
Abattoir waste meal	0	5	10	15	20
Wheat offal	12.28	11.43	11.05	10.03	9.53
Bone meal	2.7	2.7	2.7	2.7	2.7
Premix	0.25	0.25	0.25	0.25	0.25
Salt	0.25	0.25	0.25	0.25	0.25
Lysine	0.15	0.15	0.15	0.15	0.15
Methionine	0.15	0.15	0.15	0.15	0.15
ME in MJ kg ⁻¹	12.34	12.34	12.34	12.34	12.34
%CP	18.02	18.17	18.00	18.18	18.21
%CF	3.65	4.08	4.57	5.05	5.14
%Ca	1.07	1.07	1.07	1.07	1.07
%P	0.79	0.74	0.72	0.70	0.68
%Lysine	0.97	1.18	1.43	1.69	1.73
%Methionine	0.42	0.44	0.46	0.48	0.50

Production of chicken powder

At the end of the experiment, 3 birds were randomly selected from each treatment (one from each replicate), fasted overnight, and slaughtered for further processing. Immersion: the collected muscle from each treatment was deboned and cut into pieces of 8-9 cm long, weighing 80 grams. The deboned muscles of each treatment were immersed into a mixture of 100 ml of water and 200 ml of apple cider for 24 hours in the refrigerator to prolong their shelf life. Boiling: muscles from each treatment were boiled at 100 °C for 20 minutes with the addition of seasonings and spices. Drying: after boiling, each treatment was oven-dried at 175 °C for 2 hours. The broiler meat was turned alternately to achieve uniform doneness. Grinding:

each treatment was ground with the aid of electric blender (8000 watt Kenwood multifunction commercial grinder blender, made in Germany) for 1 minute to transform it to powder (Table 5). Data collection: proximate (protein, ash, ether extract, moisture content, and cholesterol) and minerals (iron, potassium, and sodium) were carried out according to AOAC (2012). Microbial loads were carried out using the procedure of Albrecht et al. (2019). Sensorial properties were evaluated according to Fakolade et al. (2018). Analyses were carried out on day 0 and 28. A total of 20 grams of each sample of chicken powder (CP) was kept on the shelf at a room temperature (24 °C) for 28 days for laboratory analysis on the 28th day.

Table 5. Ingredients for chicken powder preparation.

Ingredients	Scientific names	Quantity (gram)
Broiler meat	-	80
Garlic	<i>Allium Sativum</i> L.	2
Ginger	<i>Zingiber officinale</i> Rosc.	2
Curry	<i>Murray akenoii</i> L.	1.5
Thyme	<i>Thymus vulgaris</i> L.	1.5
Onions	<i>Allium cepa</i> L.	9.5
Salt	Sodium chloride	2.0
Maggi	Monosodium glutamate	1.5

Statistical analysis

The experimental design used for the study was a completely randomized design (CRD). All the data were

subjected to two-ways analysis of variance (ANOVA), and means were compared using Duncan's Multiple Range Test. The SPSS computer software (IBM, SPSS statistics, Chicago, U.S.A.) was used for all statistical analysis.

Results and discussion

Table 6. Proximate and mineral composition of chicken powder (CP) produced from broiler chicken fed abattoir waste (AW) in their diet at day 0.

Parameters	T1	T2	T3	T4	T5	SEM
Crude protein (g)	79.40 ^b	91.11 ^a	90.03 ^a	85.85 ^a	85.45 ^a	5.20
Ash (%)	2.14 ^c	1.98 ^c	2.06 ^c	4.20 ^a	3.50 ^b	0.12
Fat (%)	6.07 ^a	6.09 ^a	5.88 ^b	5.32 ^b	5.52 ^b	0.47
Moisture content (%)	6.11 ^b	5.76 ^c	7.01 ^a	7.12 ^a	7.11 ^a	1.33
Cholesterol (mg)	21.86 ^d	31.06 ^{ab}	26.54 ^c	29.67 ^b	33.04 ^a	4.16
Fe (mg/100g)	0.57	0.48	0.52	0.65	0.61	0.32
K (mg/100g)	18.40 ^c	16.50 ^d	19.30 ^c	21.20 ^b	23.40 ^a	2.59
Na (mg/100g)	57.20 ^d	61.40 ^c	63.40 ^{ab}	65.80 ^a	64.30 ^{ab}	3.22

Note: Different superscript letters (a, b, c, d) in the same row indicate significant differences ($p < 0.05$).

Abbreviations: T1: 0% AW used for CP, T2: 5% AW used for CP, T3: 10% AW used for CP, T4: 15% AW used for CP, T5: 20% AW used for CP, Fe: Iron, K: Potassium, Na: Sodium, SEM: Standard error of means.

From Table 6, a range of 79.40-91.11 g was obtained as the crude protein of chicken powder processed from broiler chicken fed with abattoir waste in their diet with the least crude protein for chicken powder (CP) obtained in T1. CP processed from T2-T4 appeared to have the highest with no significant ($p > 0.05$) difference. The result of chicken powder produced from T1, the control treatment (79.40 g) is in agreement with the research of Aslam et al. (2000) where the authors obtained a range of 79-83 grams when chicken powder was produced from broiler chicken. However, a range of 72-75 grams was obtained by Anderson et al. (2014). Though the values are within the same range, the variations observed could be a result of differences in the feed ingredients of the feed supplied to the broiler chicken. The high values of crude protein obtained for CP in this study especially for T2-T5, could be a result of the inclusion of abattoir waste in the diet of the broiler chicken used for its processing.

Onunkwo et al. (2018) and Sakaba et al. (2017) acknowledged abattoir waste as a rich protein source in the feed of broiler chicken. It is evident that, the quality and

quantity of feed supplied to an animal have a significant impact on the quality and quantity of meat obtained; Zhu et al. (2019) also noted that the crude protein in the feeds affects the nutritional component of the birds. High values for CP observed in this study could also be as a result of the whole broiler chicken used in the processing of CP, and this is established by the findings of Aslam et al. (2000), who found that whole broiler chicken gives a better and different result compared to when a particular part or cut is used. Geiker et al. (2021) also established that, a dehydrated meat product such as CP usually has higher amount of protein because the nutrient has been concentrated. This research agrees with the conclusion of Anderson et al. (2014) that, CP is a cheap source of protein since the protein of broiler chicken is 23-24 g (Liu et al., 2021), therefore, consumers have the opportunity of consuming high amount of crude protein when broiler chicken is processed into CP, and the inclusion of AW in the diet of broiler chicken offers a higher amount of crude protein in chicken and chicken powder.

For the ash content, a range of 1.98-4.20% was obtained and this is within the standard range, as ash content must not exceed 15% (Liu et al., 2019). Ash content is used in assessing the mineral composition in food products however, when it is present in higher quantity, it indicates older or contaminated food and presence of non-nutritive inorganic material affecting food quality and safety; and it may at times cause cancer and obesity (Liu et al., 2019). The result of this study (1.98-4.20) is consistent with that of Anderson et al. (2014) and Aslam et al. (2000), where the authors respectively obtained 5% and 6-7.50% for ash content in CP, confirmed CP as a safe product fit for human consumption.

Also, the inclusion of AW in the diet of broiler chicken does not influence the fat content of CP. T1 and T2 were significantly higher in fat with no significant ($p > 0.05$) difference while the least values for fat were observed in the CP of T3, T4, and T5. Treatments with low fat content (T3-T5) were significantly higher in moisture content with no significant ($p > 0.05$) difference. T2 that had high amount of fat, appeared to have the least moisture content (5.76%) and this is in line with the research of

Williams (2007), who stated that, the higher the fat content, the lower the moisture content. The result obtained for cholesterol indicated that CP is safe to consume (21.86-33.04 mg), because high cholesterol can cause heart diseases, stroke, and cardiovascular problems. A report by Medical News Today (2025) stated that chicken meat should not contain more than 119 mg of cholesterol and no individual should consume an amount greater than 300 mg per day (Alyse 2025). Although the result obtained in this study is higher than 6.8-7.20 mg obtained by Aslam et al. (2000), this variation could be impacted by the feeds given to the broiler chicken (Zhu et al., 2019) and differences in cooking method (Alyse 2025).

The minerals evaluated showed that, there was no significant ($p > 0.05$) difference in the Fe and K of CP across the treatments. For Na, treatments with low ash content has the lowest amount (T1-T3) while treatments with high ash content had the highest amount of Na with no significant difference. This finding is in alignment with the conclusion of Liu et al. (2019) that ash content is used in assessing the mineral content in food products.

Table 7. Proximate and mineral composition of chicken powder produced from broiler chicken fed abattoir waste in their diet at day 28.

Parameters	T1	T2	T3	T4	T5	SEM
Crude protein (g)	78.90 ^b	82.85 ^a	83.46 ^a	81.79 ^a	84.12 ^a	4.42
Ash (%)	4.60	5.00	4.52	5.27	5.17	0.92
Fat (%)	5.96	6.30	6.52	6.30	6.27	0.56
Moisture content (%)	8.11	8.33	8.79	7.46	6.89	1.96
Cholesterol (mg)	34.93	33.47	36.03	32.45	37.28	4.81
Fe (mg/100g)	1.16	1.36	1.09	1.12	1.22	0.62
K (mg/100g)	24.16	25.05	24.80	26.30	25.60	3.42
Na (mg/100g)	73.64 ^b	82.66 ^a	69.21 ^{bc}	71.32 ^b	76.32 ^b	4.01

Note: Different superscript letters (a, b, c) in the same row indicate significant differences ($p < 0.05$).

Abbreviations: T1: 0% AW used for CP, T2: 5% AW used for CP, T3: 10% AW used for CP, T4: 15% AW used for CP, T5: 20% AW used for CP, Fe: Iron, K: Potassium, Na: Sodium, SEM: Standard error of means.

It was observed in Table 7 that there were no significant changes in the nutritive value of protein and fat; however, moisture and ash content increased with an increase in storage days. When Aslam et al. (2000) stored CP for 140 days, they also observed no significant changes in the protein and fat content while rancidity, moisture, and ash content of CP increased as the product aged. A protein content of 78.90-84.12 g was obtained, with the least recorded in T1 (78.90 g). The CP processed from broiler chicken with the inclusion of AW in their diet showed no significant changes in the protein content, having a range of 81.79-84.12 g. The values obtained for protein content on day 28 for CP processed from broiler chicken fed an AW diet are not far below but within a close range of the values obtained on day 0 (85.45-91.11 g). When Aslam et al. (2000) stored CP for 140 days, they obtained 80-81 g of

protein on days 20-40, which is lower than the range of 81.79-84.12 g derived from broiler chicken fed AW-diet on day 28 of this study. This implies that AW has proven to boost the protein content of CP.

The increase in moisture and ash content confirmed the report of Aslam et al. (2000) that storage intervals can cause variation in certain components of the nutritive value. The increase in the ash content shows that the product is getting older and probably getting contaminated on the shelf during storage while the increase in moisture is an indication that the product absorbed moisture from the shelf environment, making it prone to microbial deterioration. Cholesterol and minerals evaluated (Fe, K, and Na) increased with longer storage days with no significant difference.

Table 8. Microbial load of chicken powder produced from broiler chicken fed abattoir waste in their diet at day 0.

Parameters	T1	T2	T3	T4	T5	SEM
TVC ($\times 10^{-7}$) cfu/g	5.41 ^b	5.07 ^b	4.95 ^c	6.14 ^a	6.06 ^a	0.58
TBC ($\times 10^{-5}$) cfu/g	5.03 ^b	4.66 ^c	4.29 ^d	5.75 ^a	5.58 ^a	0.57
TFC ($\times 10^{-5}$) cfu/g	1.20	1.10	1.06	1.25	1.22	0.15
TCC ($\times 10^{-1}$) cfu/g	0.65	0.50	0.39	0.71	0.55	0.08

Note: Different superscript letters (a, b, c, d) in the same row indicate significant differences ($p < 0.05$).

Abbreviations: T1: 0% AW used for CP, T2: 5% AW used for CP, T3: 10% AW used for CP, T4: 15% AW used for CP, T5: 20% AW used for CP, TVC: Total viable count, TBC: Total bacteria count, TFC: Total fungal count, TCC: Total coliform count, SEM: Standard error of means.

Chicken and chicken by-products are described as a reservoir of a variety of pathogens because they are nutrient-dense food (Zheng et al., 2022). From Table 8, based on the parameters evaluated across the treatments, it is revealed that total viable count (TVC), total bacteria count (TBC), total fungal count (TFC), and total coliform count (TCC) of CP processed from broiler chicken fed T2 (5%) and T3 (10%) inclusion of AW in their diets had the least loads of microorganisms. It can therefore be suggested that, inclusion of AW in the diet of broiler chicken should not exceed 5-10%. This is because higher level of inclusion of AW will increase the amount of protein in chicken and its products, resulting in greater susceptibility to microbial growth. T4 and T5 had the highest TVC and TBC. TVC is the number of microorganisms, especially bacteria, growing under aerobic condition; such bacteria are responsible for spoilage and deteriorative changes in meat and meat prod-

ucts (Mouafo et al., 2020). The result obtained for TVC (4.95-5.07 cfu/g) and TBC (4.29-4.66 cfu/g) at 5-10% inclusion of AW in the diet of broiler chicken used in the processing of CP falls within the standard limit of 5 cfu/g recommended by the European union (Mouafo et al., 2020). This suggests that CP has a low risk of transmission of pathogenic bacteria to consumers (Agbodaze et al., 2005).

There was no significant ($p > 0.05$) difference in the TFC and TCC across the treatments. When TCC is present in high amounts, it is an indication of unhygienic practices during processing and storage (Mouafo et al., 2020). The European Union recommends that coliform contamination should not exceed 2.5 cfu/g. The value of 0.39-0.65 cfu/g obtained in this study indicated good hygiene practices thus, endorsing chicken powder to be a safe product that can be consumed especially when it is processed hygienically.

Table 9. Microbial load of chicken powder produced from broiler chicken fed abattoir waste in their diet at day 28.

Parameters	T1	T2	T3	T4	T5	SEM
TVC ($\times 10^{-5}$) cfu/g	6.12 ^{ab}	5.45 ^b	5.20 ^b	6.96 ^{ab}	7.17 ^a	0.08
TBC ($\times 10^{-3}$) cfu/g	5.90 ^b	5.05 ^c	4.82 ^c	6.20 ^{ab}	7.03 ^a	0.85
TFC ($\times 10^{-3}$) cfu/g	1.45	1.38	1.26	1.64	1.55	0.38
TCC ($\times 10^{-1}$) cfu/g	0.72	0.59	0.48	0.91	0.66	0.11

Note: Different superscript letters (a, b, c) in the same row indicate significant differences ($p < 0.05$).

Abbreviations: T1: 0% AW used for CP, T2: 5% AW used for CP, T3: 10% AW used for CP, T4: 15% AW used for CP, T5: 20% AW used for CP, TVC: Total viable count, TBC: Total bacteria count, TFC: Total fungal count, TCC: Total coliform count, SEM = Standard error of means.

Evaluation of microbial load of chicken powder from broiler fed abattoir waste in their diet on day 28 is presented in Table 9. It was observed that, there was a slight increase in microbial activities as the storage days increased. The increase in microbial activities was not pronounced because microbial activities is always low in dried products because of low water activity (Ilansuriyan et al., 2015). A range of $5.20\text{--}7.17 \times 10^{-5}$ cfu/g was obtained for TVC. Safe level of TBC was found in 5% (5.05×10^{-3} cfu/g) and 10% (4.82×10^{-3} cfu/g) of AW in

the diet of broiler chicken with no significance difference. Although, there is no specific limit recommended for CP, the total bacteria count obtained in this study aligns with the European Union recommended limit of 5 cfu/g obtained for beef products. There was no significant difference in the TFC across the treatments. Also, no significant difference was recorded in the TCC across the treatments, indicating good hygiene measures on storage, as the values obtained were very low.

Table 10. Sensory properties of chicken powder produced from broiler chicken fed abattoir waste in their diet at day 0.

Parameters	T1	T2	T3	T4	T5	SEM
Colour	6.64 ^a	5.45 ^b	3.73 ^c	3.94 ^c	4.00 ^c	1.18
Flavour	4.82 ^b	5.91 ^a	5.10 ^a	5.18 ^a	5.36 ^a	0.17
Tenderness	5.45 ^a	5.36 ^a	4.78 ^a	3.91 ^a	4.36 ^b	0.68
Juiciness	4.09 ^c	7.42 ^a	5.18 ^b	4.09 ^c	4.64 ^c	0.17
Texture	4.55 ^{ab}	5.27 ^a	5.18 ^a	3.55 ^c	3.91 ^c	0.78
Acceptability	6.00 ^b	7.09 ^a	6.00 ^b	5.27 ^c	5.36 ^c	0.84

Note: Different superscript letters (a, b, c) in the same row indicate significant differences ($p < 0.05$).

Abbreviations: T1: 0% AW used for CP, T2: 5% AW used for CP, T3: 10% AW used for CP, T4: 15% AW used for CP, T5: 20% AW used for CP, SEM: Standard error of means.

Sensory analysis is a subjective and one of the oldest methods of checking meat quality (Table 10); it helps to identify, understand, and respond to consumer preferences more effectively (Ilansuriyan et al., 2015). Consumers select their preference by assessing the colour, flavour, tenderness, juiciness, texture, and acceptability. Colour is an important attribute that influences consumer acceptance of many foods (Ilanisuyan et al., 2015) and it is the first criterion in assessing food. The colour of CP from T1 was preferred, followed by CP from T2. The colour of T3-T5 was least accepted, with no significant ($p > 0.05$) difference. This implies that the preference and level of acceptance for colour decreased with an increase in AW in broiler chicken diet. It can thus be said that AW in the diet of broiler chicken has an impact on the colour of chicken powder.

CP produced from T2 was significantly ($p < 0.05$) higher in flavor, tenderness, juiciness, and texture, and these factors are responsible for the overall acceptance of T2 (7.09). There is no significant ($p > 0.05$) difference in the acceptance level of T1 and T3, suggesting that, inclusion of AW into the diet of broiler chicken at 5-10% does not negatively affect the sensorial properties of CP. The least juiciness, tenderness, and texture were observed at T5, indicating that inclusion of higher levels of AW into broiler feeds can affect the quality of the product by imparting coarseness, toughness, and dryness. Flavour is the perception of a consumer about a particular food product. It is interesting to note that AW does not mute the flavour or aroma of CP; it, however increases flavour, as CP becomes flavourful with an increase in inclusion level of AW.

Table 11. Sensory properties of chicken powder produced from broiler chicken fed abattoir waste in their diet at day 28.

Parameters	T1	T2	T3	T4	T5	SEM
Colour	7.66 ^a	6.00 ^b	5.00 ^c	5.66 ^c	5.66 ^c	0.24
Flavour	3.00 ^d	6.00 ^b	5.00 ^{cd}	5.66 ^c	7.00 ^a	0.24
Tenderness	4.33 ^b	5.66 ^a	5.00 ^a	4.66 ^b	4.00 ^b	0.51
Juiciness	6.00 ^b	7.00 ^a	6.33 ^b	5.33 ^c	5.33 ^c	0.28
Texture	5.66 ^a	5.66 ^a	4.33 ^b	3.66 ^c	5.00 ^b	0.31
Acceptability	7.33 ^a	7.33 ^a	7.00 ^b	5.33 ^c	7.00 ^b	0.18

Note: Different superscript letters (a, b, c, d) in the same row indicate significant differences ($p < 0.05$).

Abbreviations: T1: 0% AW used for CP, T2: 5% AW used for CP, T3: 10% AW used for CP, T4: 15% AW used for CP, T5: 20% AW used for CP, SEM: Standard error of means.

Table 11 reflects that storage days and level of inclusion have significant effect on the sensory properties of CP. The degree of colour preference of CP decreased with the inclusion of AW in the feed of broiler chicken, while the flavour of CP increased with inclusion level of AW. When the values obtained for flavour on day 0 (4.82-5.91) are compared with the values obtained on day 28 (3.00-7.00), it can be deduced that, the flavour of CP processed from broiler fed with high amount of abattoir waste (T5) increased with storage days. Upon storage, T2 maintained its quality in terms of tenderness, juiciness, and texture, which made it more acceptable and preferable. Although T1

and T2 were acceptable at the same degree, they were followed by T3 and T5. The acceptance of T5 can be attributed to its high flavour, moderate tenderness, and texture.

Conclusion

Chicken powder obtained from broiler chicken in T2 and T3 (5% and 10% AW) performed excellently when the proximate, microbial load, and palatability scores were considered. Flavour and mineral content increased with increase in abattoir waste. Inclusion of abattoir waste does not negatively affect the nutritional quality of chicken

powder but improves it, especially the protein content when incorporated at a safe level of 5-10%. Chicken powder is therefore a high protein additives, spices, or food flavouring agent, capable of improving nutritional quality of humans, while the inclusion of abattoir waste in the diet of broiler chicken offers an improved nutritive value for chicken powder.

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