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HYBRIDISATION OF YEARLING BEEF MINCE WITH *CHLORELLA* BIOMASS AND NUTRITIONAL YEAST IN A SOFT JERKY MODEL SYSTEM

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I. INTRODUCTION

Hybrid meat products offer a promising solution to improve resource efficiency and reduce the environmental impact of meat consumption. Alternative proteins, including plant-based, microbial, and algal sources, have been incorporated into hybrid formulations, though most studies have focused on conventional products like patties and sausages [1,2]. These formats often face challenges such as discolouration, poor texture, low consumer acceptance, and limited inclusion levels, especially when using microalgae like *Chlorella* due to its intense colour and distinctive flavour profiles [2]. Exploring alternative formats like snack foods could overcome these barriers by capitalising on properties less suited to conventional products. Additionally, combining multiple alternative proteins may create synergistic effects that could improve processing efficiency and functional properties allowing for higher incorporation levels. To assess the technological and sensory potential of hybrid meat, this study investigated the hybridisation of natural-fall fabricated yearling beef mince with *Chlorella* biomass and nutritional yeast in a soft jerky model system.

II. MATERIALS AND METHODS

Dairy crossbred yearling calves (10–12 months old) were processed at a commercial facility using the natural-fall fabrication method. This minimal processing approach removes all meat from the carcass in a single step, without following traditional primal or subprimal cutting specifications. Meat (7.6% fat) from the right side of each carcass was ground through a kidney plate and twice through a 3.5mm plate, vacuum-packed, and stored at -20°C. *Chlorella*-yeast (C-Y) blends were created with organic *Chlorella pyrenoidosa* (56% protein) and nutritional yeast (*Saccharomyces cerevisiae*, 47% protein) powder at ratios of 0:100 (C0-Y100), 25:75 (C25-Y75), 50:50 (C50-Y50), 75:25 (C75-Y25), and 100:0 (C100-Y0). These blends were hydrated with water (1:2 w/w) then hybridised with thawed beef mince at low (20%) and high (35%) substitution levels. Beef mince was blended (10s, twice) with 0.5% table salt using a food processor, then hand mixed with hydrated C-Y blends to form meat batters. Dry seasoning including garlic, ginger, paprika, and kawakawa (2:2:2:1, w/w) and honey were added at 1:70 and 1:49 relative to the combined weight of meat and C-Y blends, relatively, for all hybrid treatments and the control (beef mince). Batters were stabilised overnight at 4°C, formed into 3mm thick patties (~30g) using a patty maker (100mm D), and dried in a dehydrator at 65°C for 5h. Weight loss was recorded. The experiment was repeated using meat (6.7% fat) from a second animal. Meat batter pH was measured with a calibrated meat pH probe (Hanna 99163, USA). For cook loss analysis, about 25g of batter was shaped into a cylinder (3.5cm D × 1.5cm H) and cooked in a screw-capped container inside a water bath (85°C) to a core temperature of 72°C. The cook loss (%) was recorded, and its drip moisture content (%) was determined by oven drying (105°C). Other losses were calculated by subtracting drip moisture from total cook loss. Cooked batters were cut into 1cm³ cubes for texture profile analysis (TPA). Jerky moisture content was measured by oven drying (105°C), and water activity (a_w) using a water activity meter (Aqualab 4TE, USA). The instrumental colour (CIE L^*, a^*, b^*) of jerky was assessed using a Minolta Chroma Meter (CR-400, USA). Jerky strips (1×4cm) were analysed for shear force (Warner-Bratzler blade) and tensile strength (A/TG grips) using a texture analyser (TA.HD, UK). A mixed-effects model with lme4 package (R software, version 4.4.1) was used to assess the fixed effects of *Chlorella* levels (0, 25, 50, 75, and 100%) in C-Y blends and meat substitution levels (low and high) compared to the meat-only control (100% beef with seasoning and honey). Batch (1 and 2) was included as a random factor. The significance of fixed effects and their interaction was tested using ANOVA. Post-hoc comparisons were performed using predictmeans package with Benjamini–Hochberg correction ($P < 0.05$).

III. RESULTS AND DISCUSSION

No significant interactions between *Chlorella* levels in C-Y blends and meat substitution levels were observed for pH, cook loss and texture (TPA) of the batters, or tensile strength of soft jerky, thus, main effects were analysed separately (Table 1). Increasing levels of *Chlorella* in C-Y blends and meat substitution significantly raised the pH of the hybrid batters while reducing cook loss, including both drip moisture and other losses (e.g., fat, soluble proteins and minerals), indicating improved water and oil holding capacities (Table 1). All hybrid batters showed significant decreases in hardness, chewiness, springiness, cohesiveness, and resilience compared to the meat-only control,

likely due to reduced levels of structural proteins (e.g., myofibrillar proteins), especially at high substitution level. However, the *Chlorella* levels in C-Y blends did not significantly affect TPA attributes within hybrid treatments. Hybrid jerky with up to 50% *Chlorella* in C-Y blends demonstrated similar or higher tensile strength than the control, suggesting improved matrix cohesion with moderate *Chlorella* incorporation. The tensile strength decreasd significantly with higher levels of *Chlorella* in C-Y blends. The highest shear force was found in C50-Y50 at low substitution, while similar shear force values were found in meat-only control and hybrids with yeast-only (C0-Y100), as well as C25-Y75 and C75-Y25 at low substitution, and *Chlorella*-only (C100-Y0) at high substitution (Table 2). Further, hybridising yearling beef mince with *Chlorella* and yeast accelerated dehydration (higher weight losses), producing hybrid jerky with lower moisture content and a_w, thereby improving processing efficiency. Colour measurement indicated that *Chlorella* inclusion in C-Y blends led to discolouration (lower *L**, *a**, and *b**), whereas yeast-only hybrid jerky preserved redness (*a**) at low substitution with higher *L**, *a**, *b** at high substitution level.

Table 1. Effects of *Chlorella* levels in *Chlorella*-yeast (C-Y) blends and meat substitution levels on the physicochemical properties of hybrid beef batter and soft jerky. No significant interaction was observed (P > 0.05).

Attributes	Control	C-Y blends					Meat substitution levels	
		C0-Y100	C25-Y75	C50-Y50	C75-Y25	C100-Y0	Low (20%)	High (35%)
Batter								
pH	$5.66^{d, z}$	5.72^{c}	5.76^{b}	5.77^{b}	5.80^{a}	5.81^{a}	5.75^{y}	5.80^{x}
Cook loss (%)	$24.80^{a, x}$	20.93^{b}	20.51^{bc}	19.39^{cd}	19.23^{d}	17.85^{e}	21.59^{y}	17.57^{z}
Drip moisture (%)	$22.40^{a, x}$	18.86^{b}	18.49^{bc}	17.56^{c}	17.41^{c}	16.19^{d}	19.50^{y}	15.91^{z}
Other loss (%)	$2.39^{a, x}$	2.08^{b}	2.01^{b}	1.82^{c}	1.82^{c}	1.66^{d}	2.09^{y}	1.66^{z}
Hardness (N)	$46.52^{a, x}$	20.35^{b}	18.30^{bc}	15.63^{c}	18.26^{bc}	17.61^{bc}	24.64^{y}	11.42^{z}
Chewiness (N·mm)	$23.73^{a, x}$	6.02^{b}	5.55^{b}	4.60^{b}	6.03^{b}	5.50^{b}	8.78^{y}	2.30^{z}
Springiness (mm)	$0.86^{a, x}$	0.65^{b}	0.66^{b}	0.63^{b}	0.65^{b}	0.64^{b}	0.75^{y}	0.54^{z}
Cohesiveness	$0.59^{a, x}$	0.41^{b}	0.41^{b}	0.42^{bc}	0.43^{bc}	0.44^{c}	0.47^{y}	0.37^{z}
Resilience	$0.20^{a, x}$	0.11^{b}	0.11^{b}	0.12^{b}	0.12^{b}	0.12^{b}	0.14^{y}	0.09^{z}
Soft Jerky								
Tensile strength (kN/m)	$1.19^{bc, x}$	1.33^{ab}	1.15^{c}	1.40^{a}	0.97^{d}	1.04^{cd}	1.35^{y}	1.00^{z}

Different superscripts (a–e for *Chlorella* levels in C-Y blends; x–z for meat substitution levels) indicate differences from the control (100% beef with seasoning and honey) (P < 0.001).

Table 2. Effects of *Chlorella* levels in *Chlorella*-yeast (C-Y) blends and meat substitution levels (low=20%, high=35%) on the physical properties of hybrid soft jerky. Significant interactions were observed (P < 0.05).

Attributes	Control	Meat substitution levels	C -Y blends				
			C0-Y100	C25-Y75	C50-Y50	C75-Y25	C100-Y0
Weight loss (%)	56.01^{f}	Low	59.20^{bcd}	58.42^{de}	60.45^{ab}	56.79^{f}	58.92^{bcde}
		High	60.08^{abc}	59.22^{bcd}	60.89^{a}	58.78^{cdf}	57.46^{ef}
Moisture (%)	32.81^{a}	Low	22.43^{fg}	23.13^{ef}	24.41^{de}	26.41^{bc}	24.76^{cde}
		High	20.48^{gh}	25.02^{bcde}	20.39^{h}	26.76^{b}	25.60^{bcd}
a_w	0.91^{a}	Low	0.83^{cd}	0.82^{d}	0.83^{cd}	0.86^{b}	0.85^{b}
		High	0.78^{e}	0.85^{bc}	0.78^{e}	0.86^{b}	0.87^{b}
Lightness (*L**)	27.46^{c}	Low	30.55^{b}	24.82^{d}	23.83^{de}	22.85^{ef}	23.02^{ef}
		High	33.89^{a}	24.87^{d}	22.39^{f}	22.12^{f}	22.04^{f}
Redness (*a**)	4.46^{b}	Low	4.73^{b}	-0.63^{c}	-0.84^{cd}	-0.87^{cd}	-0.86^{cd}
		High	5.31^{a}	-1.25^{d}	-0.64^{c}	-0.67^{c}	-0.42^{c}
Yellowness (*b**)	7.05^{c}	Low	11.44^{b}	5.67^{cd}	4.69^{de}	3.79^{ef}	3.58^{ef}
		High	15.62^{a}	5.83^{cd}	2.46^{fg}	2.22^{fg}	1.62^{g}
Shear force (N)	24.02^{bc}	Low	26.74^{ab}	25.29^{ab}	28.33^{a}	23.93^{bc}	19.76^{de}
		High	21.41^{cd}	20.24^{de}	18.13^{e}	19.31^{de}	21.38^{cd}

Different superscripts (a–h) indicate significant differences (P < 0.05). Control = 100% beef with seasoning and honey.

IV. CONCLUSION

Hybridising natural-fall yearling beef mince with *Chlorella* and yeast proteins accelerated dehydration and reduced a_w in soft jerky, which may contribute to the processing efficiency and shelf stability. Incoporating yeast proteins with *Chlorella* (up to 50%) demonstrated synergistic effects on enhancing the structural integrity of hybrid jerky, offering a promising strategy for developing self-stable, protein-rich snacks with desirable texture.

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