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EFFECT OF STORAGE AND REFRIGERATION CONDITIONS ON THE QUALITY AND SAFETY OF PERISHABLE FOODS

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Abstract: This study examined how refrigeration temperature and storage duration affect quality and microbiological safety indicators in fresh chicken breast (Basrah, Iraq, 2026). Three samples formed a common day-0 baseline. Three independent samples were ex-amined for each combination of temperature (0, 2 and 4°C) and storage duration (2, 4 and 6 days), giving 30 sample units in total. Measurements included pH, moisture, drip loss, CIE colour coor-dinates, thiobarbituric acid reactive substances (TBARS), total viable counts, psychrotrophic counts, and yeasts and moulds. Salmonella and Campylobacter were recorded as detected or not detected in 25-g analytical units. Means and sample standard de-viations were calculated from the readings. A split-plot analysis accounted for nine refrigerators (three per temperature), with dif-ferent samples examined on successive days within each one. On day 6, mean pH was 5.955, 6.081 and 6.245 at 0, 2 and 4°C, TBARS was 0.239, 0.345 and 0.523 mg malondialdehyde/kg, and total viable counts were 5.029, 5.910 and 7.091 log10 CFU/g, re-spectively. In the exploratory refrigerator-based model, tempera-ture and day interacted for pH, TBARS, total viable counts, psy-chrotrophic counts and yellowness. Moisture changed less con-sistently than drip loss, and lightness showed no significant factor effects at the exploratory 0.05 level. Salmonella was detected in 4/27 stored samples and Campylobacter in 10/27, plus one Cam-pylobacter-positive baseline sample, with no consistent tempera-ture gradient. Quality values stayed more favourable at 0°C over six days, and the pathogen findings support continued preventive hygiene.

Keywords: Chicken breast, Refrigerated storage, Food quality, Lipid oxidation, Microbiological safety, Cold chain.

1. Introduction

Perishable foods keep deteriorating during storage and distribution, even when refrigerated. Fresh chicken breast works well for studying how small temperature differences within the refrigeration range affect quality and microbiological safety.

Mass, colour, acidity, oxidation and microbial counts don't necessarily change at the same rate. Kaewthong et al. [1] found that chilling and superchilling affected microbial counts and other quality measures in chicken breast. Ab Aziz et al. [2] reported effects of storage temperature and duration on breast meat, although their treatments also included freezing. Taken together, these studies show why quality during storage has to be described with several measurements.

Microbial quality and pathogen detection tell you different things. The FAO/WHO assessment of Campylobacter control in chicken meat [3] and the Codex hygiene texts [4,5] treat refrigeration as one part of a broader system of preventive food hygiene.

In this study, fresh chicken breast was stored at 0, 2 and 4°C for up to six days. We compared physicochemical measurements, lipid oxidation and microbial counts across temperatures and sampling days, and assessed Salmonella and Campylobacter detection descriptively. All conditions started from a common baseline, with independent samples at each storage condition.

2. Materials and Methods

2.1. Study material and setting

The experiment was conducted in Basrah, Iraq, in 2026. Fresh skinless chicken breasts were bought from a single local retail outlet in one purchase, so they formed a single procurement batch. We kept the supplier and product type consistent as far as practicable. Samples were chosen using predefined criteria, and we recorded their source, product type and purchase date. Each of the 30 experimental units came from a different bird, and portions cut from the same breast were not treated as independent replicates.

2.2. Experimental design and storage treatments

Three samples were taken at day 0 as a common baseline, before the rest were assigned to storage. The remaining design was a balanced 3 × 3 factorial: temperatures of 0, 2 and 4°C, each sampled at 2, 4 and 6 days, with three independent units per cell. This gave 27 stored units plus the three baseline units. The baseline samples were left out of the factorial analysis because they were not replicated at each temperature and so could not form three independent temperature groups.

The 27 stored units were allocated equally to the nine temperature-by-day combinations using a randomly generated order of sample IDs, and we kept a record of the allocation. Each unit was examined once, at its assigned time, and no opened sample was returned to storage for testing on another day. The three units in each condition came from different birds. Repeated portions or instrument readings from the same sample were not treated as independent units.

2.2.1. Packaging

Each unit was packed separately in a tightly closed food-grade container with air inside. No vacuum, gas mixture or preservative was used. The container type, size and closure procedure were identical for all treatments, and each package was labelled with its sample ID, storage temperature and assigned examination day. The results apply only to this air-containing packaging condition.

2.2.2. Temperature monitoring

Storage temperature was logged every five minutes by digital loggers, with probes placed at representative positions in the storage area. We recorded the actual temperatures, their mean, minimum and maximum, and any departures from target. The 0, 2 and 4°C treatments were target settings, and the logged data were used to confirm that they were reached.

2.2.3. Refrigerator allocation and experimental units

Nine independent refrigerators were used, three per target temperature: F01-F03 at 0°C, F04-F06 at 2°C and F07-F09 at 4°C. Each refrigerator held three separately packaged samples from different birds, one for each sampling day (2, 4 and 6). Within each temperature, the suffixes -1, -2 and -3 identified the first, second and third refrigerator, and this stayed the same across days. For example, F01 held T0-D2-1, T0-D4-1 and T0-D6-1, and F09 held T4-D2-3, T4-D4-3 and T4-D6-3. The same rule applies to all 27 stored samples. The three baseline samples were not assigned to refrigerators. Refrigerators were the independent storage units for temperature comparisons, while samples from successive days shared a refrigerator. The analysis distinguished biological samples from the units receiving a storage treatment [13].

2.3. Data source and sample coding

Baseline samples were coded B0-1 to B0-3. Stored samples were coded by temperature (T), sampling day (D) and replicate number, for example T0-D2-1. The descriptive analysis included all three baseline and all 27 stored samples, while the factorial analysis used only the 27 post-baseline samples.

Raw measurements, sample masses and detection outcomes were recorded in an electronic worksheet. Means and sample standard deviations were calculated from the individual measurements, and moisture content and drip loss from the sample masses. Statistical calculations used unrounded values, and results were rounded only for presentation.

2.4. Quality indicators and calculation basis

Recorded pH values were used directly. Moisture on a wet-mass basis was calculated as 100 × (wet mass − dry mass)/wet mass. Cumulative drip loss was calculated as 100 × (initial mass − final mass)/initial mass, using the paired masses recorded for the same sample. Initial mass was the mass at the start of storage and final mass the mass at the assigned sampling endpoint, so one sampling time meant one endpoint analysis, not a single weighing. Baseline drip loss was zero by definition. Initial sample masses ranged from 101.413 to 119.688 g.

Instrumental colour was expressed as the CIE coordinates L* (lightness), a* (redness) and b* (yellowness). Lipid oxidation was expressed as thiobarbituric acid reactive substances (TBARS) in mg malondialdehyde (MDA)/kg. Total viable counts (TVC), psychrotrophic counts, and yeast and mould counts were expressed in log10 CFU/g, with means and standard deviations calculated on the log scale.

Moisture and drip loss describe different aspects of water retention: moisture is the proportion of water in wet tissue, and drip loss is the cumulative mass lost relative to initial mass. These measurements were assessed alongside lipid oxidation and microbial counts [1,2]. The CIE framework specifies colour coordinates and standard viewing and illumination conditions [6], but L*, a* and b* values alone do not identify the measurement geometry used.

2.4.1. Equipment checks and calibration

Temperature logger and probe readings were compared with a calibrated reference thermometer across the study range. The pH meter, fitted with an electrode suitable for meat, was calibrated with certified buffers spanning the measurement range and checked with a verification solution. Balances of suitable precision were checked with reference weights, and reading stability was documented. The drying oven's actual temperature and uniformity were checked with a reference device.

TBARS were measured with a UV-Vis spectrophotometer. Instrument performance was checked, and each assay included a blank, a calibration curve and method-specific quality controls. The colour instrument was calibrated with its reference tile, and measurement settings were kept constant across samples.

For each instrument, the manufacturer, model, serial number, measurement accuracy and calibration date were recorded, and the verified equipment details and calibration certificates were kept with the study records. Microbiological analyses were done in a specialist laboratory that documented its equipment, assay controls and approved procedures.

2.5. Safety indicators

Salmonella and Campylobacter were recorded separately as detected or not detected in a 25-g analytical unit. For each temperature-day combination, detection frequency was the number of positive units divided by the three units tested, and the shared baseline was reported separately. Non-detection was kept as an analytical outcome and not converted to a zero concentration. ISO 6579-1 and ISO 10272-1 are reference frameworks for discussing Salmonella and Campylobacter detection [7,8], but compliance of the laboratory procedures with those standards was not established.

2.6. Statistical analysis

Continuous outcomes were summarised as mean ± sample SD, with three samples from different refrigerators in each temperature and day cell. Days 2, 4 and 6 were analysed with a balanced split-plot model. Temperature and day were fixed factors, together with their interaction, and refrigerator nested within temperature was the random storage-unit term [14]. The model was Y = μ + temperature + refrigerator(temperature) + day + temperature × day + residual. Each refrigerator contributed one different sample on each day. The model therefore accounts for the shared refrigerator, and the three samples from it are not treated as independent replicates of temperature. The common day-0 baseline was excluded.

Temperature was tested against variation among refrigerators within temperature (2 and 6 numerator and denominator degrees of freedom). Day and temperature × day were tested against the within-refrigerator residual (2 and 12, and 4 and 12 degrees of freedom, respectively). The model assumes

independent refrigerators, normally distributed errors and homogeneous variance components, with a shared refrigerator effect and independent sample residuals. A more complex temporal covariance could not be estimated reliably from this small design. $P < 0.05$ was used as an exploratory threshold, with no joint correction across the 30 factor tests. Interactions were examined before averaged factor effects. Binary pathogen results were described as counts and percentages, and no categorical significance tests were performed.

3. Results and Discussion

3.1. Physicochemical properties

3.1.1. Changes in pH

The common baseline pH was 5.838 ± 0.035. Mean pH rose with storage time at all three temperatures (Table 1), reaching 5.955 ± 0.024 at 0°C, 6.081 ± 0.058 at 2°C and 6.245 ± 0.035 at 4°C by day 6. The difference between 4 and 0°C was 0.290 pH units at day 6, compared with 0.061 at day 2. The temperature-by-day interaction remained significant after accounting for refrigerators ($F_{4,12} = 6.630$, $P = 0.005$).

Table 1. Effect of storage temperature and duration on pH. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	5.875 ± 0.034	5.917 ± 0.028	5.955 ± 0.024	5.916 ± 0.043
2°C	5.914 ± 0.015	5.970 ± 0.059	6.081 ± 0.058	5.988 ± 0.085
4°C	5.936 ± 0.037	6.093 ± 0.054	6.245 ± 0.035	6.092 ± 0.139
Average time effect	5.908 ± 0.037	5.993 ± 0.089	6.094 ± 0.131	—

Values are pH units, with n = 3 in each temperature-day cell. Common day-0 baseline: 5.838 ± 0.035 (n = 3).
Temperature and day marginal summaries are mean ± sample SD of the nine corresponding observations, excluding day 0. Marginal SDs include variation across the combined conditions. Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature <0.001, day <0.001, temperature × day = 0.005.

The effect of temperature on pH changed with storage time, and the temperatures were furthest apart by day 6. Microbial and biochemical activity may contribute to these shifts. Ab Aziz et al. [2] reported different pH behaviour over a wider range of storage temperatures.

3.1.2. Moisture content

Baseline moisture was 74.381 ± 0.109% (Table 2). Endpoint means ranged from 73.580 to 74.352%, and by day 6 moisture was 74.235 ± 0.150% at 0°C, 73.623 ± 0.302% at 2°C and 73.580 ± 0.174% at 4°C. Temperature had no significant effect ($P = 0.136$), but day did ($P = 0.016$). The interaction was not significant ($P = 0.098$).

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Table 2. Effect of storage temperature and duration on moisture content. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	74.352 ± 0.243	74.029 ± 0.181	74.235 ± 0.150	74.205 ± 0.220
2°C	74.211 ± 0.199	74.280 ± 0.188	73.623 ± 0.302	74.038 ± 0.373
4°C	74.079 ± 0.384	74.233 ± 0.370	73.580 ± 0.174	73.964 ± 0.407
Average time effect	74.214 ± 0.275	74.180 ± 0.254	73.813 ± 0.370	—

Values are % of wet mass, with n = 3 in each temperature-day cell. Common day-0 baseline: 74.381 ± 0.109 (n = 3).
Temperature and day marginal summaries are mean ± sample SD of the nine corresponding observations, excluding day 0. Marginal SDs include variation across the combined conditions.
Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature = 0.136, day = 0.016, temperature × day = 0.098.

Moisture did not fall at every sampling point. At 2 and 4°C, means rose slightly between days 2 and 4, then dropped by day 6. Moisture percentage describes tissue composition, while drip loss measures mass lost during storage, so the two need not respond in the same way. ISO 1442:2023 describes reference approaches to moisture determination in meat [9], so comparisons between studies need to take the method into account.

3.1.3. Drip loss

Drip loss increased over the recorded days at every temperature (Table 3). By day 6 it was 1.308 ± 0.113% at 0°C, 1.728 ± 0.217% at 2°C and 2.303 ± 0.247% at 4°C. The 4°C endpoint was 0.995 percentage points above the 0°C endpoint, a descriptive relative increase of about 76%. The model showed a temperature effect ($F_{2,6} = 25.027$, $P = 0.001$) and a day effect ($F_{2,12} = 82.007$, $P < 0.001$). The interaction was not significant ($P = 0.058$).

Table 3. Effect of storage temperature and duration on drip loss. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	0.615 ± 0.239	0.854 ± 0.256	1.308 ± 0.113	0.926 ± 0.356
2°C	0.797 ± 0.050	1.353 ± 0.264	1.728 ± 0.217	1.293 ± 0.441
4°C	1.041 ± 0.038	1.813 ± 0.076	2.303 ± 0.247	1.719 ± 0.566
Average time effect	0.818 ± 0.223	1.340 ± 0.456	1.780 ± 0.466	—

Values are % of initial mass. Each temperature–day cell represents n = 3. Common day-0 baseline: 0.000 ± 0.000 (n = 3).
Treatment and time marginal summaries are mean ± sample SD of the nine corresponding observations; day 0 is excluded. Marginal SD includes variation across the combined conditions.
Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature = 0.001, day <0.001, temperature × day = 0.058.

Lower drip loss at 0°C means the samples kept more of their mass over the study period, in line with the benefit of low-temperature storage in earlier chicken-breast studies [1,2]. Moisture percentage changed relatively little while drip loss increased, which shows that the two measures describe different aspects of water retention. Yi et al. [10] also examined links among oxidation, water distribution and structural changes under chilling, superchilling and freezing.

3.1.4. Instrumental colour

Colour responses differed among the coordinates (Table 4). Lightness showed no significant effect of temperature (P = 0.125), day (P = 0.113) or their interaction (P = 0.513). Redness showed significant temperature and day effects (P = 0.041 and P = 0.006) and no interaction (P = 0.723), with day-6 means of 2.374 at 0°C, 2.216 at 2°C and 2.013 at 4°C. Yellowness showed a day effect (P = 0.004) and a temperature-by-day interaction (P = 0.035), but the averaged temperature effect was not significant (P = 0.210). The interaction means the temperature contrast in yellowness depended on sampling day.

Table 4. Effect of storage temperature and duration on CIE colour coordinates.

Temperature (°C)	Day	L*	a*	b*
0	2	54.217 ± 0.681	2.700 ± 0.189	8.220 ± 0.573
0	4	53.185 ± 1.186	2.501 ± 0.071	8.320 ± 0.412
0	6	53.746 ± 0.524	2.374 ± 0.176	8.515 ± 0.835
2	2	53.801 ± 0.478	2.736 ± 0.245	8.569 ± 0.114
2	4	53.835 ± 0.705	2.390 ± 0.198	8.639 ± 0.235
2	6	53.076 ± 0.637	2.216 ± 0.279	8.832 ± 0.597
4	2	53.866 ± 0.461	2.514 ± 0.130	8.181 ± 0.039
4	4	52.540 ± 0.620	2.447 ± 0.135	9.315 ± 0.221
4	6	52.950 ± 0.880	2.013 ± 0.317	9.547 ± 0.632

Values are mean ± sample SD (n = 3). Common baseline (n = 3): L = 53.534 ± 0.695; a* = 2.605 ± 0.335; b* = 7.984 ± 0.291.*

Split-plot P values (temperature, day, interaction): L = 0.125, 0.113, 0.513; a* = 0.041, 0.006, 0.723; b* = 0.210, 0.004, 0.035.*

On day 6, mean L* was 52.950 at 4°C and 53.746 at 0°C, though the temperature effect was not significant. The observed colour shifts were lower a* and higher b*. Kaewthong et al. [1] reported comparatively stable colour under their storage conditions. Colour coordinates can therefore respond differently from microbial counts during storage.

3.2. Oxidative stability of lipids

TBARS rose from a baseline of 0.106 ± 0.027 mg MDA/kg to day-6 means of 0.239 ± 0.005 at 0°C, 0.345 ± 0.019 at 2°C and 0.523 ± 0.013 mg MDA/kg at 4°C (Table 5). The difference between 4 and 0°C was 0.062 mg/kg at day 2 and 0.284 mg/kg at day 6. Temperature and day effects were both significant (P < 0.001), as was their interaction ($F_{4,12}$ = 13.684, P < 0.001). The separation among temperatures therefore grew over the sampled interval.

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Table 5. Effect of storage temperature and duration on lipid oxidation. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	0.155 ± 0.040	0.185 ± 0.033	0.239 ± 0.005	0.193 ± 0.045
2°C	0.206 ± 0.018	0.263 ± 0.009	0.345 ± 0.019	0.271 ± 0.062
4°C	0.217 ± 0.022	0.364 ± 0.050	0.523 ± 0.013	0.368 ± 0.136
Average time effect	0.193 ± 0.037	0.271 ± 0.084	0.369 ± 0.125	—

Values are mg MDA/kg, with n = 3 in each temperature-day cell. Common day-0 baseline: 0.106 ± 0.027 (n = 3).
Temperature and day marginal summaries are mean ± sample SD of the nine corresponding observations, excluding day 0. Marginal SDs include variation across the combined conditions. Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature <0.001, day <0.001, temperature × day <0.001.

On day 6, mean TBARS at 0°C was about 54% lower than at 4°C. The rise during storage agrees in direction with the findings in [1], although assay procedures and product conditions affect comparisons of absolute values. Costa Filho et al. [11] found that oxidative markers varied with storage conditions and breast characteristics, and that some decreased during refrigeration.

3.3. Microbial quality indicators

3.3.1. Total viable counts

TVC rose from 3.377 ± 0.159 log10 CFU/g at baseline to 5.029 ± 0.175 at 0°C, 5.910 ± 0.110 at 2°C and 7.091 ± 0.130 log10 CFU/g at 4°C by day 6 (Table 6). The interaction remained significant in the refrigerator-based analysis ($F_{4,12} = 8.424$, $P = 0.002$). Temperature and day effects were also significant (both $P < 0.001$), but their averages should be read in light of the interaction.

Table 6. Effect of storage temperature and duration on total viable counts. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	3.778 ± 0.421	4.269 ± 0.253	5.029 ± 0.175	4.359 ± 0.605
2°C	3.985 ± 0.082	5.257 ± 0.126	5.910 ± 0.110	5.051 ± 0.853
4°C	4.290 ± 0.151	5.844 ± 0.309	7.091 ± 0.130	5.742 ± 1.229
Average time effect	4.018 ± 0.319	5.123 ± 0.720	6.010 ± 0.904	—

Values are log10 CFU/g, with n = 3 in each temperature-day cell. Common day-0 baseline: 3.377 ± 0.159 (n = 3).
Temperature and day marginal summaries are mean ± sample SD of the nine corresponding observations, excluding day 0. Marginal SDs include variation across the combined conditions. Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature <0.001, day <0.001, temperature × day = 0.002.

On day 6, TVC at 4°C was 2.061 log10 units above that at 0°C. Back-transformed, this is a ratio of about 115 between geometric-mean count equivalents, not a ratio of arithmetic mean colony concentrations. The difference shows that temperature control affected microbial quality even within the tested refrigeration range. Counts still rose at 0°C, though less than at the higher temperatures. Kaewthong et al. [1] also reported increasing viable counts during storage.

The day-6 mean of 7.091 log10 CFU/g at 4°C is a substantial increase in microbial load from baseline. The lower counts at 0°C show the benefit of tighter refrigeration for microbial quality over the observation period.

3.3.2. Psychrotrophic counts

Psychrotrophic counts rose from 2.867 ± 0.323 log10 CFU/g at baseline to 5.168 ± 0.257 at 0°C, 6.163 ± 0.269 at 2°C and 7.091 ± 0.283 at 4°C by day 6 (Table 7). Temperature and day effects were both significant ($P < 0.001$), as was the interaction ($F_{4,12} = 7.448$, $P = 0.003$). The difference between 4 and 0°C grew from 0.426 log10 units at day 2 to 1.923 at day 6.

Table 7. Effect of storage temperature and duration on psychrotrophic counts. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	3.749 ± 0.312	4.029 ± 0.095	5.168 ± 0.257	4.315 ± 0.683
2°C	3.948 ± 0.344	5.031 ± 0.167	6.163 ± 0.269	5.047 ± 0.987
4°C	4.175 ± 0.249	5.761 ± 0.114	7.091 ± 0.283	5.676 ± 1.280
Average time effect	3.957 ± 0.322	4.940 ± 0.761	6.141 ± 0.865	—

Values are log10 CFU/g, with n = 3 in each temperature-day cell. Common day-0 baseline: 2.867 ± 0.323 (n = 3).
Temperature and day marginal summaries are mean ± sample SD of the nine corresponding observations, excluding day 0. Marginal SDs include variation across the combined conditions. Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature <0.001, day <0.001, temperature × day = 0.003.

Psychrotrophic counts also rose more at the higher storage temperatures. Because these counts and TVC describe groups of microbes that may overlap, they were interpreted separately. Augustyńska-Prejsnar et al. [12] found that the dominant flora of chicken breast changed during refrigerated storage, along with changes in sensory quality.

3.3.3. Yeasts and moulds

Yeast and mould counts rose less than the bacterial indicators in numerical terms (Table 8). From a baseline of 1.573 ± 0.062 log10 CFU/g, day-6 means reached 2.057 ± 0.064 at 0°C, 2.362 ± 0.225 at 2°C and 2.483 ± 0.103 at 4°C. Temperature and day effects were significant ($P = 0.011$ and $P = 0.002$), but the interaction was not ($P = 0.544$).

Journal of Kyzylorda Scholarly Review
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Table 8. Effect of storage temperature and duration on yeasts and moulds. (Mean ± SD).

Storage temperature	Storage time (days)			Average treatment effect
	2	4	6	
0°C	1.863 ± 0.257	1.884 ± 0.059	2.057 ± 0.064	1.935 ± 0.164
2°C	1.952 ± 0.051	2.096 ± 0.141	2.362 ± 0.225	2.136 ± 0.225
4°C	1.992 ± 0.054	2.283 ± 0.267	2.483 ± 0.103	2.252 ± 0.259
Average time effect	1.935 ± 0.146	2.088 ± 0.231	2.300 ± 0.229	—

Values are log10 CFU/g, with n = 3 in each temperature-day cell. Common day-0 baseline: 1.573 ± 0.062 (n = 3).
Temperature and day marginal summaries are mean ± sample SD of the nine corresponding observations, excluding day 0. Marginal SDs include variation across the combined conditions.
Exploratory split-plot ANOVA (three refrigerators per temperature; days 2, 4 and 6): P for temperature = 0.011, day = 0.002, temperature × day = 0.544.

On day 6, yeast and mould counts at 4°C were 0.426 log10 units above those at 0°C, a smaller gap than for TVC and psychrotrophic counts. The microbial groups therefore responded differently to storage.

3.4. Microbiological safety indicators

3.4.1. *Salmonella* detection

Salmonella was not detected in the three common baseline samples. Among stored samples, it was detected in 2/3 units at 0°C on day 2, 1/3 at 0°C on day 6 and 1/3 at 4°C on day 4 (Table 9). All nine units at 2°C were not detected. Overall, 4/27 stored units were positive (14.8%), or 4/30 13.3%.

Table 9. Distribution of *Salmonella* detection in 25-g analytical units.

Storage temperature	Storage time (days)			All storage days
	2	4	6	
0°C	2/3 (66.7%)	0/3 (0.0%)	1/3 (33.3%)	3/9 (33.3%)
2°C	0/3 (0.0%)	0/3 (0.0%)	0/3 (0.0%)	0/9 (0.0%)
4°C	0/3 (0.0%)	1/3 (33.3%)	0/3 (0.0%)	1/9 (11.1%)
All temperatures	2/9 (22.2%)	1/9 (11.1%)	1/9 (11.1%)	4/27 (14.8%)

Cells show detected/tested (%). Each temperature-day group contains three samples, each marginal group nine, and the overall stored-sample total 27. Common day-0 baseline: 0/3 (0.0%).
Non-detection applies to the tested analytical unit and does not establish absence throughout a food lot. Results are descriptive, and no significance test was performed.

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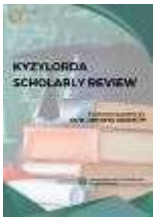

Salmonella detection showed no consistent temperature or time gradient. The results describe how often positive analytical units occurred among separately sampled breasts, and they do not show a protective effect of any temperature.

3.4.2. *Campylobacter* detection

Campylobacter was detected in 1/3 baseline samples. Post-baseline Detections totalled 4/9 units at 0°C, 3/9 at 2°C and 3/9 at 4°C (Table 10). Across stored samples the total was 10/27 (37.0%), or 11/30 (36.7%) when the shared baseline was included once. At each storage temperature, at least one sampled day had a positive analytical unit.

Table 10. Distribution of *Campylobacter* detection in 25-g analytical units.

Storage temperature	Storage time (days)			All storage days
	2	4	6	
0°C	2/3 (66.7%)	0/3 (0.0%)	2/3 (66.7%)	4/9 (44.4%)
2°C	0/3 (0.0%)	2/3 (66.7%)	1/3 (33.3%)	3/9 (33.3%)
4°C	1/3 (33.3%)	1/3 (33.3%)	1/3 (33.3%)	3/9 (33.3%)
All temperatures	3/9 (33.3%)	3/9 (33.3%)	4/9 (44.4%)	10/27 (37.0%)

Cells show detected/tested (%). Each temperature-day group contains three samples, each marginal group nine, and the overall stored-sample total 27. Common day-0 baseline: 1/3 (33.3%). Non-detection applies to the tested analytical unit and does not establish absence throughout a food lot. Results are descriptive, and no significance test was performed.

Campylobacter was detected at all three storage temperatures, which shows that retaining quality and controlling pathogens are separate matters. The FAO/WHO report [3] assesses control across the whole chicken-meat production chain, while ISO 10272-1 [8] provides a reference framework for detection. Positive detections occurred even in the treatment with the lowest final TVC and TBARS values (Tables 9 and 10). This supports the Codex approach of combining refrigeration with preventive hygiene and hazard control [4,5].

3.5. Integrated interpretation and study scope

Drip loss, TBARS and bacterial counts showed the clearest differences among storage temperatures. On day 6, their means were lower at 0°C than at 4°C, with 2°C generally in between. Lightness had no significant factor effects, and moisture was less consistently related to temperature, so the quality measurements did not respond uniformly. The findings apply to one procurement batch of chicken breast observed for six days, with three independent refrigerators per temperature and a shared baseline.

4. Conclusion

Under the tested conditions, samples stored at 0°C had the most favourable quality values over the six-day observation period. At the final sampling, mean drip loss was 1.308% at 0°C and 2.303% at 4°C, TBARS was 0.239 and 0.523 mg MDA/kg, and TVC was 5.029 and 7.091 log10 CFU/g. The refrigerator-based analysis showed that temperature contrasts for pH, TBARS, TVC, psychrotrophic counts and yellowness varied with storage duration. Lightness showed no significant factor effects, while moisture and redness followed different patterns. Salmonella and Campylobacter were found among the refrigerated samples, with no consistent detection gradient across temperatures. The pathogen findings, however, support keeping up preventive hygiene throughout storage and handling. Whether these findings hold across independent procurement batches and longer storage periods remains to be tested.

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