Investigations Into Microbiological Aspects of Poultry Processing Including Immersion Chilling, HACCP, and the Efficacy of Reprocessing

A Thesis

Submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

Charles Edward Powell

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

Food Science Department

July 1994

ISBN 0-315-92276-1

Name CHARLES EDWARD POWELL

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

FOOD SCIENCE AND TECHNOLOGY — SUBJECT TERM

0359 — SUBJECT CODE

UMI

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS
- Architecture 0729
- Art History 0377
- Cinema 0900
- Dance 0378
- Fine Arts 0357
- Information Science 0723
- Journalism 0391
- Library Science 0399
- Mass Communications 0708
- Music 0413
- Speech Communication 0459
- Theater 0465

EDUCATION
- General 0515
- Administration 0514
- Adult and Continuing 0516
- Agricultural 0517
- Art 0273
- Bilingual and Multicultural 0282
- Business 0688
- Community College 0275
- Curriculum and Instruction 0727
- Early Childhood 0518
- Elementary 0524
- Finance 0277
- Guidance and Counseling 0519
- Health 0680
- Higher 0745
- History of 0520
- Home Economics 0278
- Industrial 0521
- Language and Literature 0279
- Mathematics 0280
- Music 0522
- Philosophy of 0998
- Physical 0523
- Psychology 0525
- Reading 0535
- Religious 0527
- Sciences 0714
- Secondary 0533
- Social Sciences 0534
- Sociology of 0340
- Special 0529
- Teacher Training 0530
- Technology 0710
- Tests and Measurements 0288
- Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS
- Language
  - General 0679
  - Ancient 0289
  - Linguistics 0290
  - Modern 0291
- Literature
  - General 0401
  - Classical 0294
  - Comparative 0295
  - Medieval 0297
  - Modern 0298
  - African 0316
  - American 0591
  - Asian 0305
  - Canadian (English) 0352
  - Canadian (French) 0355
  - English 0593
  - Germanic 0311
  - Latin American 0312
  - Middle Eastern 0315
  - Romance 0313
  - Slavic and East European 0314

PHILOSOPHY, RELIGION AND THEOLOGY
- Philosophy 0422
- Religion
  - General 0318
  - Biblical Studies 0321
  - Clergy 0319
  - History of 0320
  - Philosophy of 0322
- Theology 0469

SOCIAL SCIENCES
- American Studies 0323
- Anthropology
  - Archaeology 0324
  - Cultural 0326
  - Physical 0327
- Business Administration
  - General 0310
  - Accounting 0272
  - Banking 0770
  - Management 0454
  - Marketing 0338
- Canadian Studies 0385
- Economics
  - General 0501
  - Agricultural 0503
  - Commerce-Business 0505
  - Finance 0508
  - History 0509
  - Labor 0510
  - Theory 0511
- Folklore 0358
- Geography 0366
- Gerontology 0351
- History
  - General 0578
  - Ancient 0579
  - Medieval 0581
  - Modern 0582
  - Black 0328
  - African 0331
  - Asia, Australia and Oceania 0332
  - Canadian 0334
  - European 0335
  - Latin American 0336
  - Middle Eastern 0333
  - United States 0337
- History of Science 0585
- Law 0398
- Political Science
  - General 0615
  - International Law and Relations 0616
  - Public Administration 0617
- Recreation 0814
- Social Work 0452
- Sociology
  - General 0626
  - Criminology and Penology 0627
  - Demography 0938
  - Ethnic and Racial Studies 0631
  - Individual and Family Studies 0628
  - Industrial and Labor Relations 0629
  - Public and Social Welfare 0630
  - Social Structure and Development 0700
  - Theory and Methods 0344
- Transportation 0709
- Urban and Regional Planning 0999
- Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES
- Agriculture
  - General 0473
  - Agronomy 0285
  - Animal Culture and Nutrition 0475
  - Animal Pathology 0476
  - Food Science and Technology 0359
  - Forestry and Wildlife 0478
  - Plant Culture 0479
  - Plant Pathology 0480
  - Plant Physiology 0817
  - Range Management 0777
  - Wood Technology 0746
- Biology
  - General 0306
  - Anatomy 0287
  - Biostatistics 0308
  - Botany 0309
  - Cell 0379
  - Ecology 0329
  - Entomology 0353
  - Genetics 0369
  - Limnology 0793
  - Microbiology 0410
  - Molecular 0307
  - Neuroscience 0317
  - Oceanography 0416
  - Physiology 0433
  - Radiation 0821
  - Veterinary Science 0778
  - Zoology 0472
- Biophysics
  - General 0786
  - Medical 0760

EARTH SCIENCES
- Biogeochemistry 0425
- Geochemistry 0996
- Geodesy 0370
- Geology 0372
- Geophysics 0373
- Hydrology 0388
- Mineralogy 0411
- Paleobotany 0345
- Paleoecology 0426
- Paleontology 0418
- Paleozoology 0985
- Palynology 0427
- Physical Geography 0368
- Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES
- Environmental Sciences 0768
- Health Sciences
  - General 0566
  - Audiology 0300
  - Chemotherapy 0992
  - Dentistry 0567
  - Education 0350
  - Hospital Management 0769
  - Human Development 0758
  - Immunology 0982
  - Medicine and Surgery 0564
  - Mental Health 0347
  - Nursing 0569
  - Nutrition 0570
  - Obstetrics and Gynecology 0380
  - Occupational Health and Therapy 0354
  - Ophthalmology 0381
  - Pathology 0571
  - Pharmacology 0419
  - Pharmacy 0572
  - Physical Therapy 0382
  - Public Health 0573
  - Radiology 0574
  - Recreation 0575
  - Speech Pathology 0460
  - Toxicology 0383
- Home Economics 0386

PHYSICAL SCIENCES

Pure Sciences
- Chemistry
  - General 0485
  - Agricultural 0749
  - Analytical 0486
  - Biochemistry 0487
  - Inorganic 0488
  - Nuclear 0738
  - Organic 0490
  - Pharmaceutical 0491
  - Physical 0494
  - Polymer 0495
  - Radiation 0754
- Mathematics 0405
- Physics
  - General 0605
  - Acoustics 0986
  - Astronomy and Astrophysics 0606
  - Atmospheric Science 0608
  - Atomic 0748
  - Electronics and Electricity 0607
  - Elementary Particles and High Energy 0798
  - Fluid and Plasma 0759
  - Molecular 0609
  - Nuclear 0610
  - Optics 0752
  - Radiation 0756
  - Solid State 0611
- Statistics 0463

Applied Sciences
- Applied Mechanics 0346
- Computer Science 0984
- Engineering
  - General 0537
  - Aerospace 0538
  - Agricultural 0539
  - Automotive 0540
  - Biomedical 0541
  - Chemical 0542
  - Civil 0543
  - Electronics and Electrical 0544
  - Heat and Thermodynamics 0348
  - Hydraulic 0545
  - Industrial 0546
  - Marine 0547
  - Materials Science 0794
  - Mechanical 0548
  - Metallurgy 0743
  - Mining 0551
  - Nuclear 0552
  - Packaging 0549
  - Petroleum 0765
  - Sanitary and Municipal 0554
  - System Science 0790
- Geotechnology 0428
- Operations Research 0796
- Plastics Technology 0795
- Textile Technology 0994

PSYCHOLOGY
- General 0621
- Behavioral 0384
- Clinical 0622
- Developmental 0620
- Experimental 0623
- Industrial 0624
- Personality 0625
- Physiological 0989
- Psychobiology 0349
- Psychometrics 0632
- Social 0451

Nom _____

Dissertation Abstracts International est organisé en catégories de sujets. Veuillez s.v.p. choisir le sujet qui décrit le mieux votre thèse et inscrivez le code numérique approprié dans l'espace réservé ci-dessous.

_____ ☐☐☐ U·M·I

SUJET — CODE DE SUJET

Catégories par sujets

HUMANITÉS ET SCIENCES SOCIALES

COMMUNICATIONS ET LES ARTS
Architecture 0729
Beaux-arts 0357
Bibliothéconomie 0399
Cinéma 0900
Communication verbale 0459
Communications 0708
Danse 0378
Histoire de l'art 0377
Journalisme 0391
Musique 0413
Sciences de l'information 0723
Théâtre 0465

ÉDUCATION
Généralités 515
Administration 0514
Art 0273
Collèges communautaires 0275
Commerce 0688
Économie domestique 0278
Éducation permanente 0516
Éducation préscolaire 0518
Éducation sanitaire 0680
Enseignement agricole 0517
Enseignement bilingue et multiculturel 0282
Enseignement industriel 0521
Enseignement primaire. 0524
Enseignement professionnel 0747
Enseignement religieux 0527
Enseignement secondaire 0533
Enseignement spécial 0529
Enseignement supérieur 0745
Évaluation 0288
Finances 0277
Formation des enseignants 0530
Histoire de l'éducation 0520
Langues et littérature 0279
Lecture 0535
Mathématiques 0280
Musique 0522
Orientation et consultation 0519
Philosophie de l'éducation 0998
Physique 0523
Programmes d'études et enseignement 0727
Psychologie 0525
Sciences 0714
Sciences sociales 0534
Sociologie de l'éducation 0340
Technologie 0710

LANGUE, LITTÉRATURE ET LINGUISTIQUE
Langues
- Généralités 0679
- Anciennes 0289
- Linguistique 0290
- Modernes 0291

Littérature
- Généralités 0401
- Anciennes 0294
- Comparée 0295
- Médiévale 0297
- Moderne 0298
- Africaine 0316
- Américaine 0591
- Anglaise 0593
- Asiatique 0305
- Canadienne (Anglaise) 0352
- Canadienne (Française) 0355
- Germanique 0311
- Latino-américaine 0312
- Moyen-orientale 0315
- Romane 0313
- Slave et est-européenne 0314

PHILOSOPHIE, RELIGION ET THÉOLOGIE
Philosophie 0422
Religion
- Généralités 0318
- Clergé 0319
- Études bibliques 0321
- Histoire des religions 0320
- Philosophie de la religion 0322

Théologie 0469

SCIENCES SOCIALES
Anthropologie
- Archéologie 0324
- Culturelle 0326
- Physique 0327

Droit 0398
Économie
- Généralités 0501
- Commerce-Affaires 0505
- Économie agricole 0503
- Économie du travail 0510
- Finances 0508
- Histoire 0509
- Théorie 0511

Études américaines 0323
Études canadiennes 0385
Études féministes 0453
Folklore 0358
Géographie 0366
Gérontologie 0351
Gestion des affaires
- Généralités 0310
- Administration 0454
- Banques 0770
- Comptabilité 0272
- Marketing 0338

Histoire
- Histoire générale 0578
- Ancienne 0579
- Médiévale 0581
- Moderne 0582
- Histoire des noirs 0328
- Africaine 0331
- Canadienne 0334
- États-Unis 0337
- Européenne 0335
- Moyen-orientale 0333
- Latino-américaine 0336
- Asie, Australie et Océanie 0332

Histoire des sciences 0585
Loisirs 0814
Planification urbaine et régionale 0999
Science politique
- Généralités 0615
- Administration publique 0617
- Droit et relations internationales 0616

Sociologie
- Généralités 0626
- Aide et bien-être social 0630
- Criminologie et établissements pénitentiaires 0627
- Démographie 0938
- Études de l' individu et de la famille 0628
- Études des relations interethniques et des relations raciales 0631
- Structure et développement social 0700
- Théorie et méthodes. 0344
- Travail et relations industrielles 0629

Transports 0709
Travail social 0452

SCIENCES ET INGÉNIERIE

SCIENCES BIOLOGIQUES
Agriculture
- Généralités 0473
- Agronomie. 0285
- Alimentation et technologie alimentaire 0359
- Culture 0479
- Élevage et alimentation 0475
- Exploitation des pâturages 0777
- Pathologie animale 0476
- Pathologie végétale 0480
- Physiologie végétale 0817
- Sylviculture et faune 0478
- Technologie du bois 0746

Biologie
- Généralités 0306
- Anatomie 0287
- Biologie (Statistiques) 0308
- Biologie moléculaire 0307
- Botanique 0309
- Cellule 0379
- Écologie 0329
- Entomologie 0353
- Génétique 0369
- Limnologie 0793
- Microbiologie 0410
- Neurologie 0317
- Océanographie 0416
- Physiologie 0433
- Radiation 0821
- Science vétérinaire 0778
- Zoologie 0472

Biophysique
- Généralités 0786
- Medicale 0760

SCIENCES DE LA TERRE
Biogéochimie 0425
Géochimie 0996
Géodésie 0370
Géographie physique 0368
Géologie 0372
Géophysique 0373
Hydrologie 0388
Minéralogie 0411
Océanographie physique 0415
Paléobotanique 0345
Paléoécologie 0426
Paléontologie 0418
Paléozoologie 0985
Palynologie 0427

SCIENCES DE LA SANTÉ ET DE L'ENVIRONNEMENT
Économie domestique 0386
Sciences de l'environnement 0768
Sciences de la santé
- Généralités 0566
- Administration des hôpitaux 0769
- Alimentation et nutrition 0570
- Audiologie 0300
- Chimiothérapie 0992
- Dentisterie 0567
- Développement humain 0758
- Enseignement 0350
- Immunologie 0982
- Loisirs 0575
- Médecine du travail et thérapie 0354
- Médecine et chirurgie 0564
- Obstétrique et gynécologie 0380
- Ophtalmologie 0381
- Orthophonie 0460
- Pathologie 0571
- Pharmacie 0572
- Pharmacologie 0419
- Physiothérapie 0382
- Radiologie 0574
- Santé mentale 0347
- Santé publique 0573
- Soins infirmiers 0569
- Toxicologie 0383

SCIENCES PHYSIQUES
Sciences Pures
Chimie
- Généralités 0485
- Biochimie 487
- Chimie agricole 0749
- Chimie analytique 0486
- Chimie minérale 0488
- Chimie nucléaire 0738
- Chimie organique 0490
- Chimie pharmaceutique 0491
- Physique 0494
- PolymÈres 0495
- Radiation 0754

Mathématiques 0405
Physique
- Généralités 0605
- Acoustique 0986
- Astronomie et astrophysique 0606
- Électronique et électricité 0607
- Fluides et plasma 0759
- Météorologie 0608
- Optique 0752
- Particules (Physique nucléaire) 0798
- Physique atomique 0748
- Physique de l'état solide 0611
- Physique moléculaire 0609
- Physique nucléaire 0610
- Radiation 0756

Statistiques 0463

Sciences Appliqués Et Technologie
Informatique 0984
Ingénierie
- Généralités 0537
- Agricole 0539
- Automobile 0540
- Biomédicale 0541
- Chaleur et thermodynamique 0348
- Conditionnement (Emballage) 0549
- Génie aérospatial 0538
- Génie chimique 0542
- Génie civil 0543
- Génie électronique et électrique 0544
- Génie industriel 0546
- Génie mécanique 0548
- Génie nucléaire 0552
- Ingénierie des systèmes 0790
- Mécanique navale 0547
- Métallurgie 0743
- Science des matériaux 0794
- Technique du pétrole 0765
- Technique minière 0551
- Techniques sanitaires et municipales 0554
- Technologie hydraulique 0545

Mécanique appliquée 0346
Géotechnologie 0428
Matières plastiques (Technologie) 0795
Recherche opérationnelle 0796
Textiles et tissus (Technologie) 0794

PSYCHOLOGIE
Généralités 0621
Personnalité 0625
Psychobiologie 0349
Psychologie clinique 0622
Psychologie du comportement 0384
Psychologie du développement 0620
Psychologie expérimentale 0623
Psychologie industrielle 0624
Psychologie physiologique 0989
Psychologie sociale 0451
Psychométrie 0632

INVESTIGATIONS INTO MICROBIOLOGICAL ASPECTS OF POULTRY PROCESSING INCLUDING IMMERSION CHILLING, HACCP, AND THE EFFICACY OF REPROCESSING

BY

CHARLES EDWARD POWELL

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

ACKNOWLEDGEMENTS

Sincere appreciation is extended to Dr. R.A. Gallop for his initial inspiration to gain further knowledge in water management within the food industry, and for helping to initiate this project, together with A.W. Hydamaka, through the Industry Research Assistance Program; to Bill McGill and the present management of Dunn-Rite Food Products Ltd for their valuable guidance and support; to Dr. G. Blank, advisor, for his technical assistance, constructive criticism and encouragement; to Dr. R. Holley, Head, Food Science Dept, and Dr. M. Eskin, Foods and Nutrition Dept, for their critical review of this manuscript; to the other staff, technical assistants and fellow graduate students in the Food Science Department for their support and friendship; and to Doug Milley, Shirley Dzogan and other laboratory staff at Cadham Provincial Laboratory, Winnipeg, for their confirmatory and serotyping tests. Acknowledgement is also given to relatives, friends and former fellow workmates in Australia for their practical and moral support of this venture.

This thesis is dedicated to my family, Judy, Chris and Eddie, for their perseverance and willing support throughout the project.

ABSTRACT

The final quality of ready-to-cook poultry products reflects not only the attention given to product appearance and presentation but also adherence to sound handling practices at every stage of production and processing. Microbiological aspects of broiler production including growout, transport, slaughter, defeathering, evisceration, reprocessing and chilling are reviewed. A Hazard Analysis Critical Control Point plan for biological hazards is presented. Results of an investigation into the microbiological and hydraulic aspects of immersion chilling of broiler carcasses are given. Baseline standard plate counts (SPC) and coliform counts based on whole carcass rinses were obtained for pre- and post-chill carcasses and showed a >1 log reduction as a result of immersion chilling. Reducing the volume of water per carcass at the pre-chill inside and outside (I/O) washer by 50% resulted in no significant change to post-chill carcass counts compared to the baseline. Hourly sampling of post-chill carcasses resulted in counts which were within baseline parameters after about the first hour. Results indicated that while immersion chilling rapidly reduced the carcass temperature, the actual carcass microbial load

remained fairly high. More effective use of both I/O wash- and chiller make-up water may produce further significant reductions. Canadian government regulations control hygiene and safety aspects of poultry production in federally registered establishments. At the present date, these do not permit the recovery of whole carcasses found to have post-evisceration contamination of the body cavity. Such reprocessing, as allowed in the United States, would have economic benefits for Canadian processors. In a second investigation, a cup-rinse sampling method and a reprocessing protocol were developed to test the efficacy of reprocessing. Reprocessed carcasses had bacterial counts which were not significantly different from those of inspection-passed carcasses. The detection frequencies in each group for *Salmonella* were 5 and 4%, and for *Campylobacter* were 74 and 84% respectively.

TABLE OF CONTENTS

LIST OF TABLES

PAPER No.1

PAPER No.2

LIST OF FIGURES

PAPER No.1

PAPER No.2

1. INTRODUCTION

Consumption of poultry products in many countries has increased over recent decades. For example, in Canada the *per capita* consumption in 1982 was 17.3 Kg (or 18.3% of all meat consumed) while in 1992 it was 23.1 Kg (24.3%). This increase was at the expense of beef, the consumption of which declined from 41.9 Kg (44.4%) to 35.4 Kg (37.2%) *per capita* over the same period. The total weight of eviscerated poultry produced in Canada in 1992 was 562,683,497 Kg (CCMA, 1993).

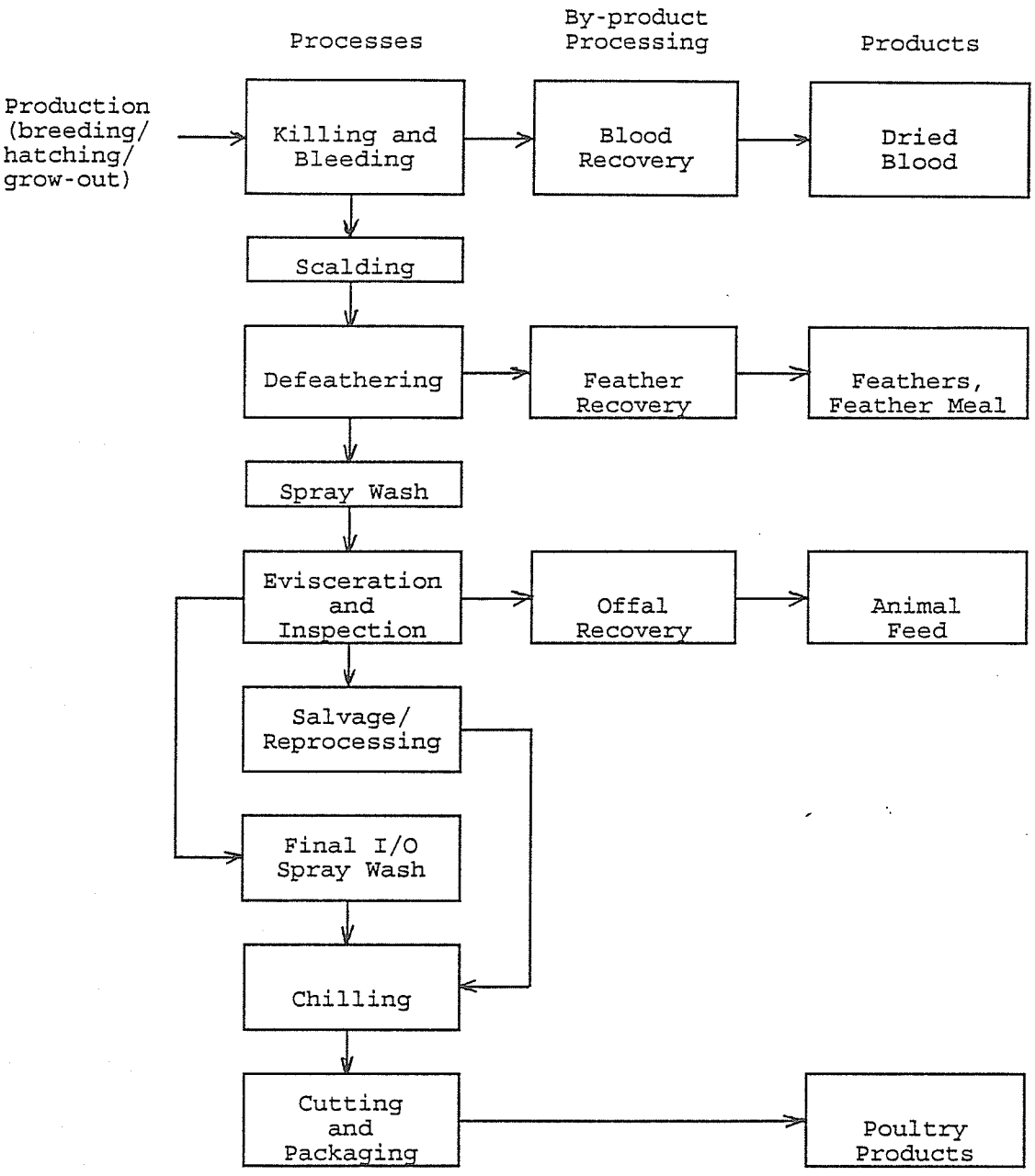
Since 1978 the production of chicken in Canada has been regulated by the Canadian Chicken Marketing Agency (CCMA); however, the actual processing is the responsibility of the individual establishments. In 1992 sixty-nine such plants operated under federal regulations and inspection for slaughtering and processing procedures. Technological advances as well as domestic and, increasingly, international competition have led to many changes in the industry. These have ranged from faster grow-out in the barn to faster line speeds and more automation in the plant. In larger plants, line speeds of 190 birds/min are not uncommon, while 60 - 72 is the norm in small to medium plants.

Efficiency improvement has resulted in a need for

increased attention in regards to the microbial status of the product. Major problems arise from the contamination of birds by microbes that are non-pathogenic to the host, but yet are pathogenic to human beings (Heidelbaugh and Menning, 1993). Numerous factors during processing contribute to microbial contamination apart from the high rate of throughput, e.g., the difficulty of removing viscera, without breakage, through a relatively small opening and the need to retain the skin, which is especially conducive to the entrapment of bacteria (Mackey, 1989). Cross-contamination can occur at virtually every stage of the process (Fig. 1), particularly at scalding, plucking, evisceration and chilling.

In an effort to control all quality and safety aspects in the processing of poultry, the adoption of the Hazard Analysis Critical Control Point (HACCP) system has been encouraged throughout the industry and plants are voluntarily implementing it. The purpose of this investigation was to review microbiological aspects of the various stages through to chilling of poultry carcasses, including HACCP, and to present results in respect to two specific processes. These concerned immersion chilling and reprocessing, and both are presented in the form of technical papers.

Figure 1. Process flow diagram for poultry processing.


Processes
By-product Processing
Products
Production (breeding/ hatching/ grow-out)
Killing and Bleeding
Blood Recovery
Dried Blood
Scalding
Defeathering
Feather Recovery
Feathers, Feather Meal
Spray Wash
Evisceration and Inspection
Offal Recovery
Animal Feed
Salvage/ Reprocessing
Final I/O Spray Wash
Chilling
Cutting and Packaging
Poultry Products

2. REVIEW OF LITERATURE

2.10 Feed Withdrawal

Withholding feed before birds are taken for slaughter is a means of reducing the natural distension of the intestines and hence the risk of gut breakage during processing (Mead, 1989). The amount and condition of the intestinal contents at the time of slaughter is of primary importance in relation to evisceration-related contamination (Wabeck,1972). According to Hewell (1994) the digestive process slows or stops once catching has begun and the birds are put into cages. Thus if the crop and/or digestive system is full of feed, it will remain so at the evisceration stage. Therefore five hours before catching is the recommended time for feed to be withdrawn. However, broilers should be left on water until the catch begins. This prevents tenderization of the gall sac which may lead to rupture and staining (Hewell, 1994).

Izat *et al.* (1989) enumerated the aerobic mesophiles and presumptive coliforms/cm^2 recovered from eviscerated and washed carcasses and related their numbers to feed withdrawal times. In each case, the count was significantly greater ($p< 0.05$) on carcasses of birds from which the feed had not been

withdrawn than those from which feed was withdrawn 12 hours prior to processing. Aerobic mesophiles (log_{10}/cm2) were reported to be 5.09 (0 hours) and 4.13 (12 hours) while presumptive coliforms were reported to be 3.11 and 2.87 respectively.

Wabeck (1972) showed that 8 to 10 hours prior to slaughter was the optimum time to withdraw feed from chickens (Table 1). Following the 12th hour there was an increased tendency towards an extreme watery condition in the intestinal tract due to a transfer of body fluids. Therefore during vent opening and evisceration, an increased risk of intestinal perforation could exist. Shane (1993) reported that feed withdrawal, ranging from 3 to 9 hours in broilers and 8 to 16 hours in turkeys, failed to influence the level of carcass contamination with *C. jejuni*.

Experience has also shown that the stress of handling and the transportation of poultry resulted in increased defecation. This, combined with the perforated walls of crates or cages, can ensure prolific cross-contamination. Studies have shown the importance of effective sanitation of trucks and crates in preventing *Salmonella*-free flocks from becoming infected. For example, Rigby *et al.* (1982) showed that 46% of birds from a *Salmonella*-free broiler flock became contaminated during transportation and that 99% of the crates had yielded salmonellae before the flock was loaded.

TABLE 1. Average visual scores for fecal contents[1] in the intestine for birds withdrawn from feed and water for various time periods prior to slaughter.

	Visual scores	
Time (hrs)	Trial 1	Trial 2
4	2.03	2.57
8	1.40	1.67
10	-	1.57
12	1.63	1.80
24	1.80	2.00

[1]1 = None, 4 = large amount.

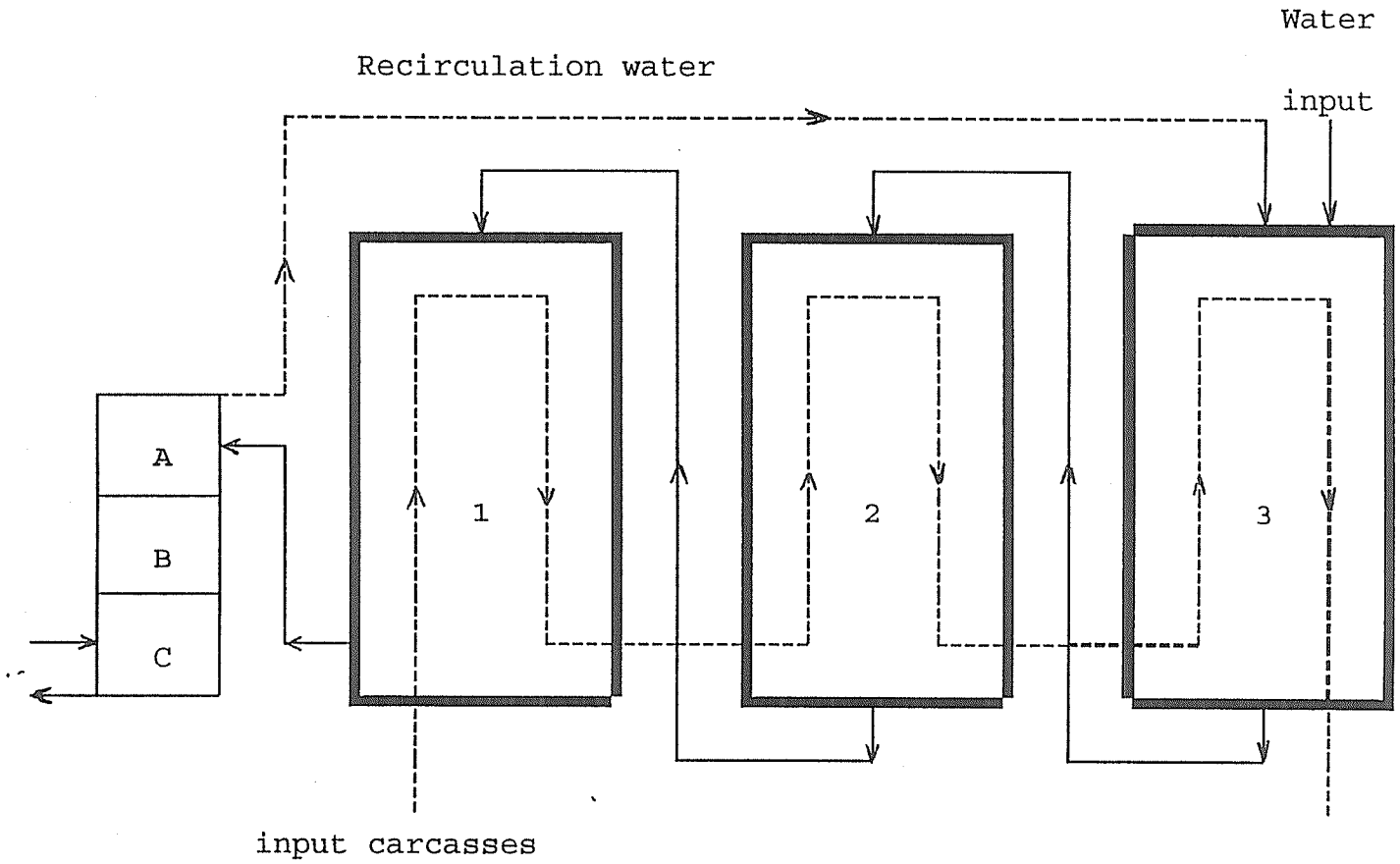
2.11 Scalding

Veerkamp (1992) reported that traditional hard scalding, at 60°C, reduced the carcass bacterial load 100-fold and that soft scald, at 50-55°C, resulted in a 10-fold reduction. Further, he demonstrated that an additional 100-fold reduction was effected by using a three-stage counter-current system as illustrated in Fig. 2. In this process, water is supplied to tank 3, where birds exit, and flows via tank 2 to tank 1. It then passes through a plate heat exchanger where it is pasteurized at 75°C for 20 seconds and cooled to 55°C before being returned to tank 3.

Krizner (1993) described a new scalder design which is in commercial use. This Hydro-fall Scalder (Johnson Food Equipment, Kansas City, MO) has a multi-stage counter-flow arrangement which utilizes an initial section that cascades water over the birds prior to immersion scalding. By washing the majority of the dirt from the birds, a much cleaner final scald results. The second counter-flow section consists of three separated lanes. Dividers extend to the bottom of the tank and make-up water is added at the exit end through a final spray cabinet. Thus birds progesssively move into cleaner water.

In a study to determine the effect of several processing modifications, including counter-current scalding, Waldroup *et*

Figure 2. Three-stage scalding scheme with heat exchanger for recirculated water; A = recuperation section, B = holding section, C = heating section.


Water
Recirculation water
input
A
B
C
1
2
3
input carcasses

al. (1992) reported a reduction in aerobic plate counts in the five plants monitored. However, the overall average reduction was less than 0.5 log. The specific contributions made by the modification in the scalder was not assessed.

James *et al.* (1992b) reported a significant decrease in bacterial counts as a result of counter current scalding. Although this reduction was maintained at the pre-chill and post-chill stations the incidence of *Salmonella* increased during immersion chilling. The microbial results from whole carcass rinses are given in Table 2.

The efficacy of additives, including organic acids such as acetic, lactic and propionic, to increase or decrease the pH of the scald water have been investigated in an attempt to increase the thermal death rate of organisms. For example, Mead (1989) reported reductions in the $D_{52\,C}$ (decimal reduction time at 52°C) value of *S. typhimurium* from 35 to 0.6 min. using glutaraldehyde at 0.5%.

2.12 Defeathering

The contaminating effect of mechanical defeathering arises from two aspects of the process. One is the aerosol created in the vicinity of the machines and the other is the microbial growth which thrives on the rubber "fingers". Both result in extensive cross-contamination and are aided by the

TABLE 2. Mean $\log_{10}$ colony-forming units per carcass for whole carcass rinse[1] samples before (baseline) and after installation of a countercurrent scalder and a postscald hot-water rinse cabinet.

Location	n	APC[2]	Enterobacteriaceae	*Escherichia coli*	Salmonellae (%)
Baseline					
Preevisceration	160	4.05	3.07	2.17	58
Prechill	160	3.39	2.29	1.46	48
Postchill	158	3.14	2.32	0.87	72
Scalder changes					
Preevisceration	99	3.73*	2.70*	2.09	24*
Prechill	99	3.18*	2.25	1.61	28*
Postchill	49	2.87*	1.56*	0.89	49*

[1]200 ml phosphate buffer.
[2]Aerobic plate count.
*Significant ($p<0.01$) decrease from the corresponding number in the baseline study.

warm moist environment created by the nearby scalder (Mead, 1989). The ability of *S. aureus* to colonize feather pickers and multiply even during the processing operation was reviewed by Mead and Dodd (1990) and is illustrated in Table 3. The relatively high level of sub-surface counts reveals why some bacterial strains become "endemic" to the processing plant.

Notermans *et al* (1982) demonstrated an increase in *S. aureus* on skin from 10 CFU/g to $>10^3$ CFU/g due to plucking and evisceration.

In a study of the microtopography of turkey skin following different methods of defeathering, Kim and Doores (1993a) concluded that bacterial attachment and subsequent removal depended on the condition of the skin surface produced by the particular method.

The conventional system involving automatic picking by mechanical pluckers following immersion of birds in a hot scalding tank (58°C) produced a relatively smooth surface. In the kosher defeathering system, where birds were immersed in cold water (7-10°C) then mechanically plucked, a rough, scaly skin surface resulted due to retained keratinized epidermal layers. Thirdly, a steam-spray defeathering system incorporating simultaneous steam and hot water (62°C) spraying during mechanical feather removal, produced skin which had a highly wrinkled microtopography. The strength of attachment (Sm value) for bacteria was found to be significantly lower

TABLE 3. Surface and sub-surface contamination of rubber 'fingers' from poultry defeathering machines after in-plant cleaning.

Machine	Finger no.	Degree of wear	Surface counts (log_{10} cfu/cm^2) TVC[1]	Surface counts (log_{10} cfu/cm^2) *Staphylococcus aureus*	Sub-surface counts (log*10* cfu/g) TVC	Sub-surface counts (log*10* cfu/g) *Staphylococcus aureus*
A	1	none	5.1	3.4	4.1	2.9
	2	none	6.1	3.5	3.6	<2.0
	3	slight	5.6	3.1	5.5	2.6
B	1	slight	5.0	3.4	5.5	3.3
	2	moderate	>6.1	>6.0	>6.0	>5.0
	3	substantial	5.6	3.8	5.3	3.0
C	1	substantial	5.9	5.3	4.4	3.1
	2	slight	5.8	5.1	5.5	4.8
	3	substantial	5.0	4.2	5.5	4.6

Data of Thompson and Paterson, 1983; cited by Mead and Doddd, 1990.
[1]TVC = total viable count.

for the skin following conventional defeathering, due to its smoother surface, than for the other two methods.

In a further study, Kim and Doores (1993b) observed greatest development of bacterial fimbriae and irreversible attachment with the steam-spray skin, and the least with the hydrophobic *stratum corneum* layers of the kosher skin, following incubation. The difference sharply increased after 10 minutes incubation. There was no significant difference ($p<0.01$) between conventional and kosher skin, even after 60 minutes.

Campylobacter jejuni was also shown to be more prevalent on carcasses after defeathering. Baker *et al.* (1987) reported that 90 to 100% of the carcasses from four plants were positive for the organism after scalding and defeathering although only 20 to 100% of the live birds had *C. jejuni* on the skin.

Izat *et al.* (1988) reported that, following a significant decrease in *C. jejuni* on the carcasses, as a result of scalding, the count increased again during defeathering. The average count (log_{10}; CFU/1000 cm^2) in three poultry plants were pre-scald, 3.44; post-scald, 1.27 and post-pick, 2.96.

2.13 Washing

In addition to the washing effect of scald water and

sprays used in defeathering, further spray washing occurs immediately after the pickers, after transfer to the evisceration line, prior to chilling and by immersion chilling itself.

Notermans *et al.* (1980) demonstrated that extra spray-washers along the evisceration line could restore microbial counts to post-picking levels. The effect of omitting post-evisceration spray-washing compared with that of one, two or three sites on the level of *Enterobacteriaceae* is shown in Table 4. The greatest effect was observed when spray-washers were used after opening the carcasses, after exposure of the intestines and after removal of the organs. In this study, 0.4 L/carcass was used at each spray washer.

Cleaning carcasses after evisceration and before chilling is mandatory in EEC countries and North America. Amounts up to 1.5 L/2.5 kg carcass are required to be sprayed under pressure (Mulder, 1984). A spray washer is the term used when only the outside of the carcass is washed; in contrast, in an inside and outside (I/O) bird washer a probe enters and washes the body cavity while the exterior is sprayed by external nozzles. Results indicated that the latter type was no more effective than the former one in terms of its effect on the total aerobic and *Enterobacteriaceae* counts when compared to mechanical evisceration (Mulder, 1984). It was reported that rinsing carcasses with 2 to 4 litres of water removed up to

TABLE 4. Effect of spray-cleaning during evisceration on the *Enterobacteriaceae* contamination of carcasses.

Experiment	*Enterobacteriaceae* (log_{10} mean count/g skin)				
	after defeathering		after evisceration		
	n	count	n	count	Difference[2]
Without additional spray-cleaners (A)	20	3.66±0.36[1]	27	4.97±0.40[1]	1.04
With spray-cleaning after removal of organs (B)	15	3.57±0.33	15	4.38±0.43	0.48
As (B) with spray-cleaning after exposure of intestines(C)	15	3.57±0.33	15	3.88±0.38	0.12
As (C) with spray-cleaning after opening carcasses (D)	20	3.66±0.36	19	3.70±0.31	0

[1]Standard deviation.
[2]Log_{10} difference at 0.90 confidence limit.

89% of the attached bacteria (Forsythe and Waldroup, 1992).

Technical data for the Johnson 1/0 Birdwasher V-T (Johnson Food Equipment, Kansas) specify water usage rates of 100 to 106 L/min (at 3.4 to 4.1 BARS) for eviscerating and 151 to 174 L/min (at 6.9 to 8.3 BARS) for reprocessing (washing carcasses to remove visible contamination from the body cavity). At a line speed of 72 birds/min this translates to about 1.5 L/bird for eviscerating and 2.5 L/bird for reprocessing. Canadian regulations require a minimum of 2.0 L/2.5 Kg bird be used for post-evisceration washing and chilling combined - provided an overflow is maintained during immersion chilling (Agriculture Canada, 1982).

2.14 Chilling

Poultry chilling throughout North America is almost exclusively performed by immersion in refrigerated water with or without functional additives. According to Mulder (1984) poultry carcasses in European community countries are either immersion-chilled or air-chilled depending whether they are to be marketed frozen or refrigerated respectively.

Mead (1989) reported reductions of 50-90% for both coliform and total viable counts during properly controlled immersion chilling. While immersion chilling reduces total counts through the washing action, it also serves to

redistribute organisms (Lillard, 1990). For example, the incidence of *Salmonella* containing carcasses increased from 10% at pre-chill to 37.5% at post-chill (Table 5).

The air-chilling operation uses cold air as the coolant so that the chilled carcasses are dry and do not suffer leaching losses (Veerkamp, 1985).

A more recent development is evaporative chilling. During chilling by air, water is sprayed on the carcass at various stages. This process takes advantage of the cooling effect of evaporation while preventing net moisture loss from the carcass. A water usage of only 0.7 L/carcass has been reported for this method (Vranic *et al.* 1991).

No differences were found in experiments in which the microbiological condition and shelf-life of air- and evaporative- chilled products were compared (Mulder, 1984). However, Vranic *et al.* (1992) demonstrated a significant decrease (>1 log) in counts for air-spray chilling compared to a slight increase (<1 log) during immersion chilling.

Air scrubbing is sometimes used in conjunction with immersion chilling and involves incorporation of air under pressure in the chill water. This results in improved agitation and effects solids removal as foam, including bacteria. Dickens and Cox (1992) demonstrated that carcasses inoculated with a marker strain of *Salmonella typhimurium* and subjected to air scrubbing had significantly ($p<0.05$) more

TABLE 5. Levels of aerobic bacteria, Enterobacteriaceae, and *Salmonella* incidence before and after chilling on fully processed broilers from two commercial processing plants[1].

Sampling point	Mean $\log_{10}$ CFU/carcass ± SD				*Salmonella* incidence (%)	
	Aerobic bacteria		Enterobacteriaceae		no. positive/no. sampled	
	Plants		Plants		Plants	
	A	B	A	B	A	B
Prechill	6.69 ± 0.36a	6.67 ± 0.30a	6.01 ± 0.41a	6.09 ± 0.29a	5/40 (12.5)a	4/40 (10.0)a
postchill	5.78 ± 0.19b	5.94 ± 0.20b	4.97 ± 0.29b	4.97 ± 0.23b	11/40 (27.5)a	15/40 (37.5)b

[1]Means based on 40 samples per sampling point.
Means (and incidence) in columns which are not significantly different ($p>0.05$) are followed by the same letter.

organisms removed than those with water only. Carcasses (90%; 32/40) which were immersed in water for only 30 minutes were *Salmonella*-positive while the level was only 22% (9/40) for carcasses immersed in air-agitated (air scrub) water for the same period. Although aerobic plate counts and *Enterobacteriaceae* counts were not significantly different ($p<0.05$), a significant difference in moisture pick-up by air-scrub carcasses (13.9%) was obtained compared to those subjected to immersion only (5.8%).

The major advantage of immersion chilling to the processor is uptake of moisture by the carcass, resulting in increased yield. In Canada, the moisture gain must not exceed 8% of the weight of the eviscerated carcass prior to the inside-outside washer (Agriculture Canada, 1982). The actual net weight gain due to moisture pick-up for the packaged product is more likely to be only 2-3% (Hewell, 1994).

The chilling of poultry meat was comprehensively reviewed by Thompson *et al.* (1974) who reported that the results of investigations into the effectiveness of immersion chilling in reducing carcass microbial counts were conflicting. Factors contributing to these differences could include bacterial contamination on carcasses before chilling, the amount of water overflowed and replaced per carcass, and the ratio of birds to water in the chiller.

2.14.i Chlorination

To ensure the wholesomeness and quality of processed poultry products, chemical disinfection is widely used as an adjunct to chillng to control microbial populations in chiller water and to improve the shelf-life of finished products (Tsai *et al.*, 1992). Chlorine, in the form of hypochlorous acid, has been the chemical most commonly used. Other compounds suggested as disinfectants have included ozone (Sheldon and Brown, 1986; Chang and Sheldon, 1989), chlorine dioxide (Baran *et al.*, 1973; Lillard, 1980), hydrogen peroxide (Lillard and Thomson, 1983), and food acids (Thomson *et al.*, 1976).

Canadian regulations permit the chlorination of chiller make-up water to a maximum 20 ppm (Agriculture Canada, 1982). Masri (1986) reported the use by some poultry operations of super-chlorination, whereby enough chlorine is added so as to maintain about 5 ppm free chlorine in the discharged overflow.

In general, poultry microbiologists consider a treatment successful if a 2-log reduction is obtained (Lillard, 1993). Tsai *et al.* (1992) reported that chlorine dosages of 100 to 150 ppm were required to reduce the number of bacteria in chiller water by at least 99% (i.e., 2 logs) within 3 to 5 min in laboratory tests. The authors also reported that chiller water contained 0.35% solids, which consisted of lipids (56%), ash (33%), and total nitrogen (4.2%), and which contributed to the high chlorine demand.

Although chlorine and chlorine dioxide have been shown to significantly reduce microbial counts in chiller water, carcass counts were only slightly (<1 log) reduced (Thiessen *et al.*, 1984; Lillard, 1980; Lillard, 1993). Lillard (1993) reported that sonification in combination with a chlorine solution with 0.5 ppm free residual chlorine reduced *Salmonella* counts on broiler breast skin by >2 log after a 15 sec. treatment.

Other treatments, aimed more at water conservation but also microbial control, have included some form of disinfection in a chiller water recycle/reuse process. These are reviewed by Clarke (1984) who studied the use of activated carbon for this purpose. He found that powdered activated carbon was unsuccessful for bacteriological control for recycled chiller water. In addition to the abovementioned treatments, processes incorporating purely physical means (Picek, 1992) have proved successful in reconditioning chiller water to acceptable microbiological quality for reuse.

Recently it was stated that there will always be the possibility that plants employing immersion chilling will begin to switch more and more to air chilling for water conserving and other reasons (Anon, 1994a). One Canadian plant began air chilling poultry in 1988 and has since increased its throughput to 400,000 carcasses per week (Anon, 1994b).

2.15 Evisceration

Evisceration techniques in most plants are fully mechanized. The steps involved include vent opening and viscera removal; however, the uneven sizes of birds processed can result in gut breakage with traditional automatic equipment.

Mead (1989) reported that a collaborative study in six EEC countries involving eleven broiler processing plants revealed that evisceration significantly increased the level of coliform bacteria in only two of the plants. There was no apparent difference between plants using manual evisceration and those with automatic equipment. However, the fact that conclusions were based on results of neck-skin counts could make their significance questionable since evisceration accidents are more likely to affect the visceral cavity and vent region.

Thayer and Walsh (1993) reported that the percentage of carcasses contaminated due to intestinal tract rupture at evisceration varied from 0.5 to 5.0% with a mean of 1.0%. These carcasses were removed for reprocessing, nevertheless the potential exists for the probes which contacted the fecal or ingested matter to contaminate subsequent carcasses, if not sanitized adequately between draws.

Notermans *et al.* (1980), showed an increase in

Enterobacteriaceae contamination during evisceration (Table 4). In this case skin from around the cloaca was macerated for analyses, resulting in a difference of greater than 1 log cycle.

2.16 Reprocessing

According to Thayer and Walsh (1993) the contamination of carcasses by fecal or ingested matter during the evisceration process is one of the major problems in the processing of poultry. Factors relating to gut breakage have been mentioned in previous sections.

When identified at an inspection station, a contaminated carcass is removed from the main processing line and reprocessed. In the United States, this involves whole carcass retrieval. In some plants, the carcass is hung back on the reprocessing line which conveys the carcasses to a reprocessing area; in other plants movable racks are used. Reprocessing may involve automatic equipment such as cabinet or inside-outside bird washers. Alternatively, it may be accomplished manually, using spray washing by hand, vacuuming with "lung-guns", and removal of contaminated tissue. Some plants use a combination of methods. Reprocessed carcasses are inspected again and manually dumped into the chiller.

In Canada, in the case of inspection detected

contamination of the internal cavities, certain parts only may be salvaged. Provided facilities permit expeditious and hygienic operations, legs, wings and breast meat, at least, may be recovered. The washing of contamination from exposed tissue other than skin is not acceptable in lieu of trimming (Agriculture Canada, 1982).

Blankenship *et al.* (1975) demonstrated, to the satisfaction of the USDA, that the microbiological quality of contaminated-condemned carcasses could be made indistinguishable from passed carcasses by on line internal washing with tap water. Sampling methods in the study included external swab of the breast skin, internal swabbing of the anterior visceral cavity lining, internal cavity rinse with 100 mL of sterile 1%(W/V) sodium citrate, and a whole carcass rinse with 500 mL of sterile 1%(W/V) sodium citrate. The US regulation subsequently permitting reprocessing required the use of 20 mg/L (ppm) available chlorine in the spray wash water (Federal Register, 1978).

Theissen (1985), in a Canadian study related to reprocessing, used the same internal rinse method, as well as swabbing the internal obturator muscle (located below the tail head in the visceral cavity). Mean counts (total plate and coliforms) were consistently higher on reprocessed carcasses compared to approved carcasses sampled after an I/O washer.

This study also reported better efficiency in terms of

microbial counts for off-line manual reprocessing over on-line reprocessing through automatic I/O washers. The mean counts were generally 1 log cycle higher for the latter. However, the overall conclusion was that a change to the regulation concerning reprocessing in Canada could not be justified. Contributing to this conclusion was the fact that reprocessed carcasses consistently failed re-inspection (visual examination by Federal inspectors to ensure removal of particulate matter) at a significantly higher rate than approved carcasses.

Thayer and Walsh (1993) assessed the potential for cross-contamination by the automatic viscera remover if carcasses detected with internal contamination were allowed to remain on the process line for reprocessing by existing 1/O washers. There was no difference ($p > 0.05$) in the aerobic plate count between the swab taken of the probe before entry into a contaminated carcass after cleaning, and of the next probe to pass through the brush cleaners.

2.17 Line Speed

The nature of poultry processing allows for a high degree of automation. Economics also demands a trend towards increased automation and consequently maximum line speeds. The rate of processing may exceed 6000 birds/hour, with some

plants operating at 10,800 birds/hour. Under such conditions process control is critical and optimum hygienic handling must be compromised.

The fact that each carcass must be inspected restricts branch-line speeds to 30-36 carcasses/minute. This still does not permit enough time for hand washing or knife sanitizing after each contact. Automatic equipment, however, may be relatively more effectively controlled in terms of cross-contamination potential. Thayer and Walsh (1993) examined the risk of cross-contamination if carcasses tagged for reprocessing remained on the line and were passed through the same automatic equipment as approved carcasses. In particular, they concentrated on the probes which enter the visceral cavity to effect viscera removal after inspection. It was reported that cross-contamination due to the probes was not a problem when they were rinsed with 20 ppm chlorinated water in combination with brushing.

Canadian regulations allow for veterinary inspectors to request management to decrease the line speed if the carcass contamination rate exceeds 3%, to permit satisfactory dressing procedures and post mortem inspection (Agriculture Canada, 1982).

It has been predicted that line speeds will be further increased as major visual tasks are automated. Colour computer vision systems are expected to be available to perform

automatic grading, post mortem screening (sensory inspection) and house quality inspection, with off-line manual confirmation and reworking still necessary (Anon, 1994a).

2.18 Microbial Pathogens

Live birds carry large numbers of microorganisms both on their skin and feathers and in their intestines. However, according to Mulder (1984), only two groups of microorganisms are important in processed poultry.

The first group consists of potentially pathogenic microorganisms, particularly salmonellae, *Campylobacter jejuni*, *Staphylococcus aureus* and *Clostridium perfringens*. The second group of microorganisms, consists of the pigmented and non-pigmented pseudomonads, *Acinetobacter* and *Moraxella*; the organisms are able to grow at low temperature and cause spoilage (Mulder, 1984).

The risk of food poisoning, with all its consequences, is a major concern. An estimate as high as $2,200 million has been made for the cost of food poisoning in Canada (Todd, 1987). During the 5 years preceding 1992, chicken was reported to be responsible for 45% of the *Salmonella* foodborne outbreaks reported to the Centre for Disease Control, Atlanta, Ga., USA. Recently a study in Seattle, Washington, found that 50% of the reported cases of *Campylobacter* infections were

attributable to poultry (Potter, 1992).

Obviously, relying on sensory inspection to control microbial hazards is not the answer since they cannot be seen. Control procedures that minimize the bacterial contamination that occurs during laying, in the hatchery, during the growout operation, and during processing must be and are being instituted. Secondly, it is necessary to implement various techniques to maximize decontamination by reducing or removing bacterial contamination that is simply unavoidable (James *et al*. 1993).

Competitive exclusion (CE) has received much interest as a pathogen control measure since first introduced by Nurmi and Rantala (1973). In this procedure, gut flora from *Salmonella*-free adult birds are orally administered into the gut of newly hatched chicks so that the pathogen is competitively excluded from colonizing the intestine. Subsequent research with CE for controlling *Salmonella* and *Campylobacter* during broiler production has been comprehensively presented by Blankenship (1991). Commercial-scale trials involving CE in Sweden (Wierup *et al*, 1988), the Netherlands (Goren *et al*, 1988), and the US (Blankenship *et al*, 1993) demonstrated significant decreases in the incidence of *Salmonella* contamination during growout but were not 100% effective. The results of these studies indicated reductions from 1.35 to 0.73%, 3.5 to 0.9% and 11 to 2% respectively. Obviously the potential for further

contamination and cross-contamination remained. Table 6 lists examples of the numerous points of potential cross-contamination which exist in the various stages of poultry processing (May, 1974).

Other production control measures have concentrated on barn hygiene, including feed, water, litter and rodent and insect control. In addition, Bailey (1988) lists age, the level of stress on the bird, the health of the birds, the type and amount of feed additives, and the genetics of the bird as factors affecting the susceptibility of chickens to Salmonellae colonization.

2.18.i *Salmonella*

The natural habitat of *Salmonella* is the intestinal tract of humans and animals. Three different syndromes in humans are caused by different types of *Salmonella*. The most severe is typhoid fever, caused by *S. typhi* for which humans are the only reservoir. The second is enteric fever, caused by *S. paratyphi*, *S. schottmuelleri* and *S. hirschfeldii*. The most common type of salmonellosis is a gastroenteritis syndrome (food poisoning) caused by all the other types of *Salmonella*. More than 2300 serotypes are presently known and all are considered pathogenic (Doyle and Cliver, 1990).

Salmonellae are gram-negative, non-sporeforming rods; most are mobile by peritrichous flagella. They are facultatively anaerobic with a growth range between 6 and 45°C

TABLE 6. Some points of potential cross-contamination in poultry processing plants.

1. Receiving and hanging.
   a. Bird to bird in coops
   b. Air in holding sheds.
   c. Coops.
   d. Hands of hangers.
   e. Dust and air in hanging area
   f. Shackles and rail dust.
2. Killing.
   a. Bird to bird.
   b. Air.
   c. Killing machine or knife.
   d. Shackles and rail dust.
3. Scalding and defeathering.
   a. Scald water.
   b. Picking fingers.
   c. Condensate.
   d. Air.
   e. Bird to bird.
   f. Pinners' hands.
   g. Hock cutter.
   h. Belt for rehang.
   i. Shackles and rail dust.
   j. Rehang operators' hands.
4. Evisceration.
   a. Employees' hands, inspectors' hands.
   b. Knives and other cutting instruments.
   c. Machine contact surfaces.
   d. Air.
   e. Shackles and rail dust.
   f. Bird to bird.
   g. Non-cutting instruments.
   h. Belts and chutes.
   i. Giblet flumes and water.
   j. Hang back racks.
5. Chilling.
   a. Chill water.
   b. Ice.
   c. Bird to bird.
   d. Air.
   e. Elevators.
   f. Belts and chutes.
   g. Giblet to giblet.
6. Grading.
   a. Employees' hands.
   b. Belts.
   c. Shackles and rail dust.
   d. Bird to bird.
   e. Air.
7. Ice packing.
   a. Employees' hands.
   b. Packing bins.
   c. Bird to bird.
   d. Air.
   e. Ice.
   f. Packing material.
   g. Giblet or neck to carcass.
8. Cut-up.
   a. Employees' hands.
   b. Knives.
   c. Saws or power knives.
   d. Bird to bird.
   e. Part to part.
   f. Air.
   g. Belts, bins, pans, etc..
   h. Shackles and rail dust.

and a pH range of 4.1 to 9.0. In addition to conventional taxonomy, the salmonellae are also classified on the basis of serology. Serology is based on the O or somatic antigen, the H or flagellar antigen, and the Vi or capsular antigen. There are also fimbriae antigens that occur at the cell surface. They are also called F antigens or type 1 pili and are suggested as adhesion factors that allow the organism to colonize surfaces.

Thomas and McMeekin (1981) described the effects of water-induced changes on the microtopography of chicken muscle facia and their significance in the contamination /decontamination of *Salmonella*. The authors reported that collagen associated with the connective tissue expands on exposure to water, forming a dense network of fibres to which bacteria were shown to attach. Absence of fimbriae (or pili) from test bacteria suggested that these structures were not involved in attachment to collagen fibres. Also, the motility status of the organism did not influence attachment. It was concluded from this study that the bacterium-collagen fibre interaction is a function of the ionic environment of the muscle tissue since sodium chloride was shown to prevent attachment and cause detachment. Dickson and Anderson (1992), however, included motility due to the presence or absence of flagella or fimbriae, along with relative negative charge on the cell wall and relative hydrophobicity as intrinsic

properties of the bacterial cell affecting attachment to tissue surfaces.

Sanderson *et al.* (1989) suggested that hyaluronic acid (HA) was a potential receptor site for adhesion. A 37,000 dalton outer membrane protein was shown to be involved in the specific binding of HA to the surface of *Salmonella* spp. and other *Enterobacteriacea*. Thomas and McMeekin (1981) suggested that sodium chloride may prevent attachment to collagen fibres by reducing the viscosity of the mucopolysaccharide matrix, thereby allowing elution of this material before attachment could take place. Also, they reported that low concentrations of sodium chloride (ca 0.05 M) dramatically reduce the viscosity of HA.

Bacterial attachment to tissue surfaces is a complex phenomenon which is generally considered a two-step process. The initial, reversible attachment to the surface by physical forces is followed by a more permanent, irreversible attachment regulated by bacterial production of extracellular polysaccharides (Dickson and Anderson, 1992). This glycocalyx has been studied on chicken surfaces by Matilla and Frost (1988) using a scanning electron microscope (SEM). They reported that the polysaccharide glycocalyx differs in form depending on the bacteria, and that its solubility varies. Also, that while it may be highly structured, and thus helps maintain colony shape, it is also highly hydrated, thereby

protecting the colony and aiding nutrient flow.

The glycocalyx can be either a slime- or a capsular-type. According to Kosaric *et al.* (1987) the slime-type glycocalyx results whenever there is loose bonding of the exopolysaccharides to the underlying cell wall. These slime layers can be readily lost with shear forces. In contrast a capsular-type glycocalyx is usually associated with a tighter binding to the cell wall.

Substrate and environmental conditions will obviously have an effect on slime or capsule formation. Gill and Newton (1978) listed glucose and amino acids as utilizable nutrients from meat tissue, and pH, water activity, temperature and competition between organisms as important factors.
Lillard (1989a) concluded that bacteria, including salmonellae, are firmly attached to the skin when birds first enter the processing plant. However, contamination resulting from processing steps will be more readily removed if insufficient time is allowed for strong attachment.

Lillard (1989a) reported that even after 40 consecutive whole carcass rinses, levels of bacteria recovered were still within 1 log of those recovered by the first rinse.

The incidence of *Salmonella*-positive birds arriving at processing plants was reported to be 3 to 4% on average while the level was 35% for fully processed carcasses (Lillard, 1989b). Surkiewicz *et al.* (1969) reported 20.5% of broiler

carcasses in a 9 plant survey to be positive for *Salmonella*, both before and after chilling. In a similar survey in 1979, the result was 5.5 and 11.6% respectively (Campbell *et al.* 1983).

James *et al.* (1992a) reported that 43 and 46% of the carcasses examined before and after immersion chilling with 25 ppm chlorine respectively were positive for *Salmonella*. Without chlorine the incidence levels were 48 and 72% respectively. The results indicated that chlorination reduced cross-contamination during chilling, however, the results also supported the finding of Lillard (1993) that attached/entrapped salmonellae were not readily accessible to chlorine.

A survey of two integrated broiler plants by Jones *et al.* (1991a) found 21.4% of whole processed carcasses to be positive for *Salmonella* although the incidence was only 10.7% at the chiller exit, suggesting cross-contamination by workers and/or equipment. (However, given the current knowledge of bacterial attachment, it is quite possible that 100% of processed carcasses, from known positive flocks, are supporting at least one *Salmonella* organism or colony.) This survey also traced the incidence of *Salmonella* at each stage of broiler production including breeder/multiplier and broiler houses, feed mills, hatcheries and insects and mice at each location. The data suggested that insects mechanically

transport the organism and that a comprehensive approach is needed to control *Salmonella* contamination.

Forsythe and Waldroup (1992) reviewed the microbiological hazards associated with poultry. They reported incidence rates for carcasses with *Salmonella* at about 36% over more than a 20 year period starting from 1967, despite all the research effort aimed at reducing the incidence.

Fecal matter is considered to be the main source of *Salmonella* contamination of broilers in the processing plant (Lillard, 1989b).

2.18.ii *Campylobacter*

Butzler and Oosterom (1991) stated that *Campylobacter jejuni* is the most frequent cause of bacterial gastroenteritis in man, and that there is a significant correlation between the handling and consumption of poultry meat and the occurrence of *Campylobacter enteritis.*

C. jejuni are gram-negative, slender (0.2-0.5 um wide by 0.5-5 um long), spirally curved rods, and are motile with a single polar flagellum (at one or both ends) that is two to three times the length of the cell. Motility is a unique darting, corkscrewlike movement. When cells form short chains, they appear as S-shaped or gull-winged. The organism is catalase and oxidase positive but cannot ferment or oxidize carbohydrates (Doyle, 1990).

Unlike other recognized foodborne pathogens, *C. jejuni* is a strict microaerophile that requires low levels of oxygen for growth; growth is retarded or inhibited at oxygen concentrations less than 3% and greater than 10-15%; 5% appears optimal. Additionally, *C. jejuni* is a capnophile (carbon dioxide lover) that grows well in the presence of 10% CO_2, but not well, if at all, in less that 5% CO_2. The optimum temperature for growth is 42-45°C and survival is enhanced at refrigeration temperature (5°C). Depending on the environment, growth medium, and initial number of *C. jejuni*, the organism may survive in a non-growth environment (e.g., pH 4.5) for several weeks at 4°C (Doyle, 1990).

Reservoirs of *C. jejuni* include a wide variety of wild and domestic warmblooded animals. Surveys frequently reveal *C. jejuni* in feces of 30-100% of poultry tested (Doyle, 1990). In a Canadian study, Munroe *et al.* (1983) found that, of 108 chickens sampled, all contained *C. jejuni*. As with *Salmonella*, *C. jejuni* infection mostly appears to be devoid of clinical manifestations in poultry (Franco, 1988).

Water was identified as the carrier leading to an outbreak of human campylobacter enteritis (Vogt *et al.* 1982). In another case involving children who suffered diarrheal illness, the cause was traced to magpies which had pecked the caps of milk bottles (Anon., 1993). Both of these examples have implications for broiler production depending on the

source and treatment of the water used.

Stern and Line (1992), compared three methods for the recovery of *Campylobacter* spp. in retail carcasses and found that 98% were positive. Similarly, high incidences were reported for processed carcasses by Yildiz and Diker (100%; 1992), Baker *et al.* (100%; 1987), Berndston *et al.* (93%; 1992), while 52% was reported by Jones *et al.* (1991b). In the latter survey a primary source of the organism could not be determined.

Yildiz and Diker (1992) found that scald water samples were 100% negative while chill water samples were 100% positive and proposed defeathering as the first contamination step. Izat *et al.* (1988) also showed scalding to be effective in significantly decreasing *C. jejuni* numbers (>1.84 logs).

Wassenaar *et al.* (1993) studied the role of flagella in the colonization of chick caeca by *C. jejuni*. Motility was found not to be a prerequisite, although the nature of the flagellin did have an effect on the colonization potential. In particular, a 100-fold increase in colonization was observed in organisms with flagellin A compared with those with flagellin B. This is of importance in the use of CE as a control measure against *Campylobacter*. These efforts were reviewed by Blankenship (1991). Park *et al.* (1991), however, did not consider the rearing of *Campylobacter*-free flocks to be economically realistic. Instead they suggested improvement

of processing procedures such as reducing the amount of available water on carcasses by drying or addition of solutes as more likely means of reducing the incidence of campylobacters. Specifically, they proposed investigation into the effect of washing carcasses in strong brine.

C. jejuni was found not to survive the salting, rinsing, and chilling operations in a kosher processing plant (Baker *et al.* 1987). In this study, 100 cm^2 of breast skin was swabbed for the microbiological analyses.

Berndtson *et al.* (1992) proposed feather follicles as an orifice through which *C. jejuni/coli* could be introduced to subcutaneous layers. This would enable them to survive disinfectant treatments that could be effective against surface flora. Surface swabbing as a sampling technique may therefore not give a true indication of the presence of the organism.

Leutchefeld and Wang (1981) reported that 34% of turkey carcasses were positive for *Campylobacter* after overnight chilling in chlorinated water. They reported that increasing the chlorine content in the chiller water from 50 to 340 ppm did not cause a decrease in the number of *C. jejuni*-contaminated carcasses.

2.18.iii *Escherichia coli*

Organisms of this species are gram-negative,

facultatively anaerobic, non-sporeforming rods and are generally motile by peritrichous flagella. Their optimal temperature for growth is 37°C with a temperature range for growth of 10 to 40°C. The optimal pH for growth is 7.0 to 7.5, with the minimum at pH 4.0 and the maximum at pH 8.5 (Frazier and Westerhoff, 1988). Many strains produce capsules and generally ferment lactose. Most strains of *E. coli* are harmless, but a few are pathogenic.

The four principal groups of *E. coli* implicated in foodborne disease are: enteropathogenic, enteroinvasive, enterotoxigenic and enterohemorrhagic. The latter group includes the strain 0157:H7 which is considered the most important in terms of foodborne disease. Humans are the principal reservoir of the first three types, while cattle serve as a reservoir for 0157:H7 (Doyle and Cliver, 1990).

E. coli, when used in a study related to bacterial attachment to poultry surfaces by Firstenberg-Eden *et al.* (1978), demonstrated a rate of attachment that was 3-5 times greater than that of salmonellae; in addition they were less easily removed by spray washing. Notermans and Kampelmacher (1974) reported an optimum temperature of 21°C and an optimum pH of 8.4 for attachment of *E. coli* to chicken skin. The authors concluded that these environmental conditions had the greatest effect on flagella activity.

Doyle and Schoeni (1987) isolated *E. coli* O157:H7 from

only 1.5% of poultry and other meats at the retail level in the USA. Surkiewicz *et al.* (1969) reported six or fewer *E. coli*/cm^2 on the skin of chilled, eviscerated chickens which was not significantly different from levels reported by Campbell *et al.* (1983). This level represented a count/carcass (log_{10}) of about 4.0 and may be compared with a count of 3.2 reported by James *et al.* (1992a) for chilled carcasses. Pre-chill counts/carcass (log_{10}) of 3.9 and 4.0 were reported by James *et al.* (1992a) and Blankenship *et al.* (1993) respectively.

2.18.iv *Staphylococcus aureus*

Staphylococcus aureus is important in relation to poultry meat hygiene because of its ability to produce enterotoxins which may cause food poisoning in humans. The organism is gram-positive, requires an organic source of nitrogen and is a facultative anaerobe. They are salt-tolerant (10 to 20% NaCl) although a sub-lethal heat treatment decreases tolerance to salt. The temperature range for growth and toxin production is about 4 to 46°C, while the pH range for growth is pH 4.8 to pH 8.0. Staphylococci are ordinarily present in low numbers and usually are outnumbered by competing bacteria in raw foods (Frazier and Westerhoff, 1988). *Staphylococcus aureus* occurs on the skin and in the nasopharynx of live birds and a high proportion of carcasses become contaminated during processing.

Numbers rarely exceed 10/cm^2 but can sometimes reach 100-1000/cm^2 (Mackey, 1989).

Levels of *S. aureus* have been shown to greatly increase during defeathering by automatic pickers (Mead and Dodd, 1990). Strains can become endemic and survive most sanitation procedures. The ultimate origin of "endemic" strains of *S. aureus* is unclear (Mead and Dodd, 1990).

Notermans *et al.* (1982) studied six processing plants for *S. aureus* presence and found that each one was associated with endemic strains belonging to different phage types, none of which was found on the incoming birds. The ability of endemic strains to produce mucoid growth, and their tendency to grow in clumps aided attachment and chlorine resistance (Mead and Dodd, 1990, Dodd *et al.* 1988).

Using a whole carcass rinse, Vorster *et al.* (1994) found a mean count (log_{10}) of 3.1/ml on raw broilers from a retail outlet.

2.18.v *Listeria monocytogenes*

Listeria monocytogenes is a small (1.0-2.0um x 0.5um), gram-positive nonsporeforming, non-acid-fast, diptheroid-like rod with round ends. It is facultatively anaerobic, motile at room temperature, and hemolytic. It is very salt tolerant and can survive for 4 months in a solution of 25.5% NaCl held at 4°C. The organism grows better in an atmosphere containing

about 5% oxygen and 5-10% CO^2 than in air. *L. monocytogenes* is psychrotrophic and thrives at refrigeration temperatures, although its optimum range is 30-37°C. *L. monocytogenes* is widespread in the environment and has been isolated from soil, dust, animal feed, water, sewage, and most animals (Bahk and Marth, 1990).

Waldroup *et al.* (1992), in a study involving six broiler processing plants, reported the presence of *L. monocytogenes* on post-chill carcasses from three of the plants after improved processing procedures were adopted; in contrast, four of the plants were positive for the organism before the modifications. Significant reductions in two plants were from 75.9% and 58.9% to 29.2% and 18.8% respectively. Additional surveys for the detection of *L. monocytogenes* include incidence rates of: 61% in Norway (Rorvik and Yudestad, 1991), 10 to 43% in three U.S. plants (Bailey *et al.*, 1984), 59% in the U.K. (Hudson and Mead, 1989), 48% in New Zealand, 47% in Denmark and 25% in Switzerland (Johnson *et al.*, 1990).

Bernard (1994) identified effective control measures for *L. monocytogenes* such as: regular cleaning and sanitizing of product contact surfaces, the use of low-pressure water for rinsing and cleaning to minimize the generation of bacterial mists, application of a product sanitizing rinse and/or blanch step, and prevention of recontamination of products; and noted that these procedures would also minimize the potential for

contamination by other pathogens.

2.18.vi Pathogen Control

Heidelbaugh and Menning (1993) proposed a goal of pathogen-free fresh meat and poultry to be widely available by the year 2000. To achieve this end they suggested the implementation of a safe and effective system of pasteurization analagous to that used by the dairy industry. Relevant and available state-of-the-art techniques could include utilizing chlorination, heating, modified atmosphere packaging, pH adjustment, radiation or surfactants. Similarly, Mossel and Struijk (1993) have advocated "transradiation" of fresh meat and poultry by irradiation (3 kGy) to eliminate unavoidable natural pathogens.

Regulations have been proposed by the USDA Food Safety and Inspection Service which would require all meat and poultry packages to be labeled with refrigeration, storage, cooking, and handling instructions. It was calculated that if this resulted in a 3% reduction in foodborne illness the saving would be $40 million per year (Voelker, 1994).

The Canadian Chicken Marketing Agency (CCMA) has developed a "comprehensive code of practice" incorporating a bio-security program with the objectives: to reduce bacterial load on carcasses; to maintain confidence in the product; and to reduce the risk of serious problems in the future. Part of

the program includes testing each barn for pathogens at least once a year (Anon. 1994b).

2.19 Hazard Analysis Critical Control Point (HACCP)

An outbreak of food poisoning in January 1993, which resulted in the deaths of three children and more than 500 other people becoming ill, has led to a major revamp of the USDA's Federal Meat Inspection Act (Kelly, 1993). In that instance *E. coli* 0157:H7, in improperly cooked ground beef was the cause; however, all pathogens are being targeted in the new prevention-based systems. The emphasis is to be on scientific microbial control as opposed to traditional sensory assessment procedures. The installation of HACCP programs has been emphasised as a major component in the strategy.

Agriculture Canada is also in the process of implementing its Food Safety Enhancement Program (FSEP) of which HACCP is the foundation. It will apply to all processed foods. Thus the models being prepared apply to ready-to-eat products. However, to the extent that chilled eviscerated poultry provides the raw materials for further processing, then HACCP must also be applied to it.

Of major concern regarding programs responsible for food safety, is evolving microorganisms and the increasing complexity of monitoring them in our food supply (Heidelbaugh

and Menning, 1993). HACCP was designed in the 70's to be the optimal method for ensuring control of a food manufacturing process and represents a systematic approach to food safety, wholesomeness, and prevention of economic adulteration (Adams, 1990).

The seven basic principles of HACCP are:

(1) Assess microbiological, chemical and physical hazards and prevention methods at each step in the food chain.

(2) Determine the critical control points (CCP).

(3) Define the critical limit requirements at each CCP.

(4) Establish procedures for monitoring each CCP

(5) Determine corrective actions for deviations at each CCP.

(6) Determine verification procedures for the HACCP system.

(7) Establish effective record keeping and documentation.

Microbiological aspects of a HACCP plan for poultry processing will now be presented.

2.19.i Hazard Identification

From practical knowledge of the processing operation, a process flow diagram is constructed on which each step is

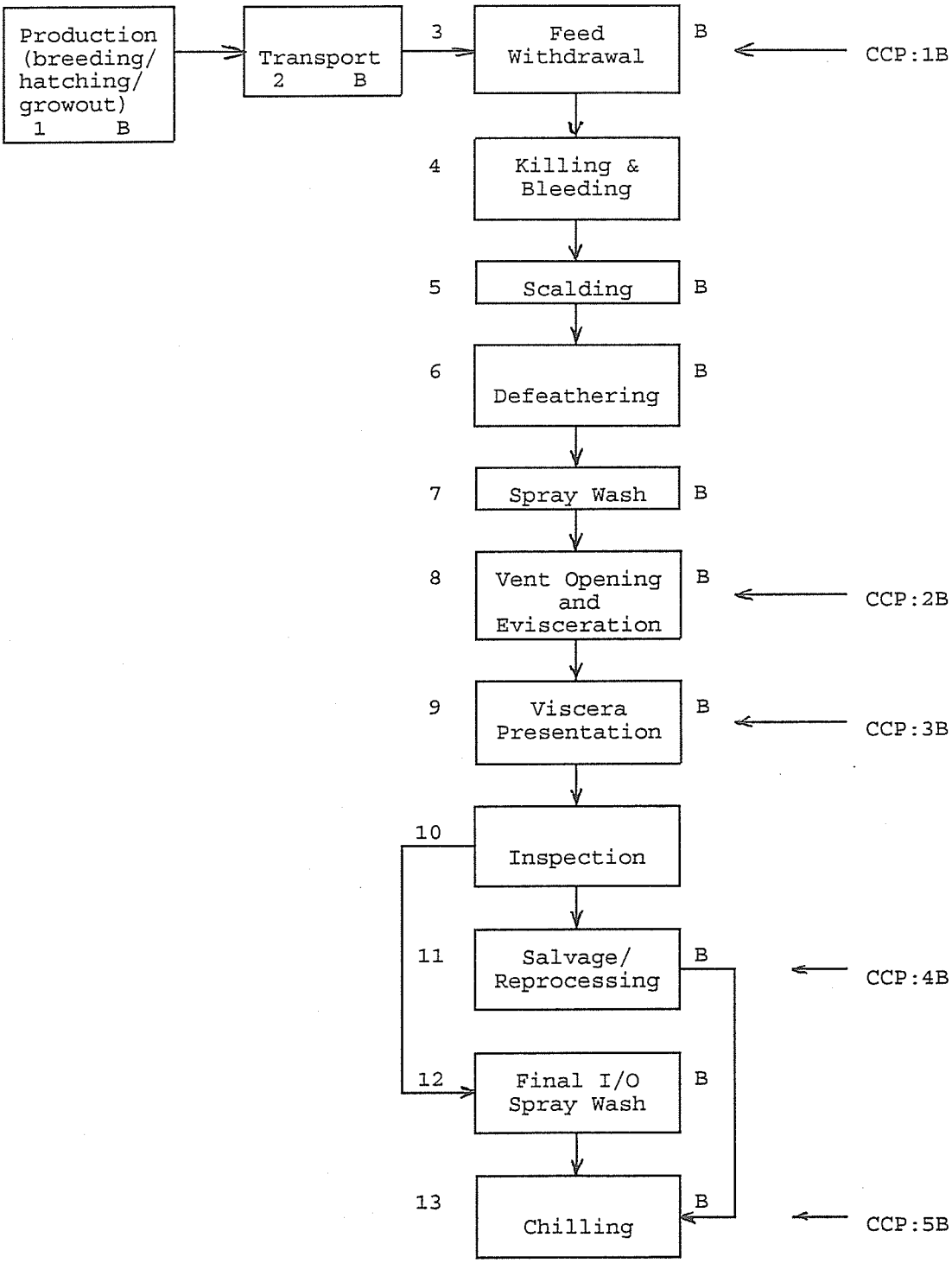
assigned a number. This is shown in Fig. 3. The process is reviewed by careful observation and by reference to resource information to determine at which steps a hazard exists. This is indicated on the flow diagram beside the step by adding "B" for biological. (A complete analysis would also include "P" for physical and "C" for chemical hazards.)

Wholesomeness and safety of poultry are based in part on the health of the live animals, their feed, and the environment under which they are raised (Anon., 1985). Drug and pesticide residues are examples of potential chemical hazards which may be found in poultry meat. The type, quantity, and time of application of antibiotics constitute CCPs on the farm. A microbiological hazard may result if antibiotic-resistant strains of pathogens emerge as a result of such treatments.

The state of feed and water with respect to presence of infectious agents, toxic chemicals, or mycotoxins may also represent CCPs. Thus proper storage of grains and meals to prevent mold growth and mycotoxin production is critical, as is barn sanitation, including water treatment and litter management.

Hazards for which the processor is responsible would result from temperature abuse and/or gross contamination. Thus the chilling stage and subsequent temperature control, and factors which affect fecal contamination during evisceration

Figure 3. Process flow diagram for chilled eviscerated poultry showing critical control points.


Production (breeding/ hatching/ growout)
1 B
Transport
2 B
3
Feed Withdrawal
B
CCP:1B
4
Killing & Bleeding
5
Scalding
B
6
Defeathering
B
7
Spray Wash
B
8
Vent Opening and Evisceration
B
CCP:2B
9
Viscera Presentation
B
CCP:3B
10
Inspection
11
Salvage/ Reprocessing
B
CCP:4B
12
Final I/O Spray Wash
B
13
Chilling
B
CCP:5B

may be considered CCPs.

Each potential hazard is identified as in Table 7: The "Controlled at" column is completed at a later stage.

2.19.ii CCP Determination

A critical control point is any step at which control can be applied and a food safety hazard can be prevented, eliminated or reduced to an acceptable level. Each hazard may not necessarily be a CCP. However, actions must be taken to ensure elimination, prevention or reduction of all identified hazards (Agriculture Canada, 1994).

The determination of CCPs is accomplished by applying the "decision tree" as shown in Table 8 to each identified hazard. Where a hazard is adequately controlled by an existing prerequisite program, e.g., sanitation, personnel training, equipment maintenance, etc., this fact is noted in the second column. Questions 1 to 4 are then answered consecutively and reveal whether or not a CCP exists. In the last column the CCPs are noted with a designated number. The five CCPs serve the purpose of this exercise, although production (breeding, hatching, growout) (Roberts,1992), and scalding/defeathering and washing (Roberts, 1992, and Varnam and Evans, 1991) have also been identified. The "Controlled at" column in Table 7 is completed by indicating how hazards are controlled.

TABLE 7. Hazards identification for chilled eviscerated poultry.

Identified biological hazards	Controlled at
Infection/disease during growout	Barn hygiene program
Sub-optimal feed withdrawal	CCP:1B
Truck/crate contamination	Sanitation P/P
Contamination at scalding/picking	Maintenance P/P Training P/P
Inadequate washing after rehang	"
Contamination at vent opening/ evisceration	CCP:2B
Contamination due to viscera presentation	CCP:3B
Contamination at salvage/reprocessing	CCP:4B
Contamination missed at I/O washer	N/A
Contamination at immersion chiller	CCP:5B

P/P = Prerequisite program
CCP = Critical control point
I/O = Inside/outside
N/A = Not applicable

TABLE 8. HACCP form with decision tree for CCP determination for chilled eviscerated chicken (Cont. pp 54 and 55).

CCP DETERMINATION						
Process step	Category and Identified Hazard Determine if fully controlled by P/P[1](s). If yes = indicate P/P and proceed to next identified hazard. If no = to Q1	Q1. Could a control measure(s) be used at any process step? If no = not a CCP Identify how this hazard will be controlled before and after the process + proceed to the next identified hazard. If yes = description + Q2.	Q2. Is it likely that contamination with the identified hazard could occur in excess of the acceptable level or increase to an unacceptable level? If no = not a CCP + proceed to the next identified hazard. If yes = Q3.	Q3. Is this process step specifically designed to eliminate/reduce the likely occurrence of the identified hazard to an acceptable level? If no = Q4. If yes = CCP + go to last column.	Q4. Will a subsequent step eliminate the identified hazard or reduce likely occurrence to an acceptable level? If no = CCP + go to last column. If yes = not a CCP + identify subsequent step + proceed to next identified hazard.	CCP Number Proceed to next identified hazard
Growout	(B) Disease/ Infected birds. Yes. Barn Hygiene P/P. Ante/Post mortem inspection					
Feed withdrawal	(B) Risk of gut too full of feed. No	Yes. Rearrange kill schedule.	Yes	Yes		CCP:1B

Truck/ crate	(B) Risk of contamination Yes. Sanitation P/P					
Scalding/ Defeathering	(B) Risk of contamination Yes. Maintenance P/P, Training P/P.					
Washing after rehang	(B) "					
Evisceration	(B) Gut rupture. No.	Yes. Salvage/ reprocessing	Yes.	Yes.		CCP:2B
Viscera presentation	(B) Gut rupture and cross contamination No.	"	Yes.	Yes.		CCP:3B
Salvage/ reprocessing	(B) Incomplete removal of contamination and cross-contamination No.	Yes. Reinspection	Yes.	Yes.		CCP:4B

I/O[2] bird washer	(B) Loss of adjustment. No.	Yes. Regular performance checks.	No. Temporary failure remedied by prechiller.			
Immersion chiller	(B) High temperature/ low water make-up rate. No.	Yes. Rapid chilling (ice), regular performance checks.	Yes. Carcass may exit at excessive internal temperature.	Yes.		CCP:5B

[1]P/P = Prerequisite program.
[2]I/O = Inside/outside.

It is recognized that poultry carcasses carry a base microbial load which includes pathogenic organisms. Provided proper in-plant and food-handling procedures are followed prior to consumption, potential hazards can be eliminated. Under these circumstances then, application of the CCP decision tree (Mayes, 1992), as shown in Fig. 4, would mean no biological CCPs exist in the production of raw poultry products. In practice, however, spoilage can occur and cross contamination takes on increased importance if hazards during production are not controlled.

Chilling is controlled by proper adherence to potable water make-up rates, overflow requirements, and monitoring of temperatures and refrigeration performance. Factors which impact on the increased possibility of fecal contamination have been discussed, particularly feed withdrawal and evisceration.

The processor must program feed withdrawal times to suit the daily kill schedule. For example, 5 to 6 hours prior to catching (Nunas, 1988; Hewell, 1994) and 8 to 10 hours prior to slaughter (Wabeck, 1972) are optimum. Water should be left available until catching (Nunas, 1988). Times must be communicated to the respective growers, drivers and loading crews. A log should be kept, recording feed withdrawal and catch times per barn and copies returned with each truck for plant management scrutiny. Fig. 5 represents a possible format

Figure 4. Critical control point decision tree: raw materials.

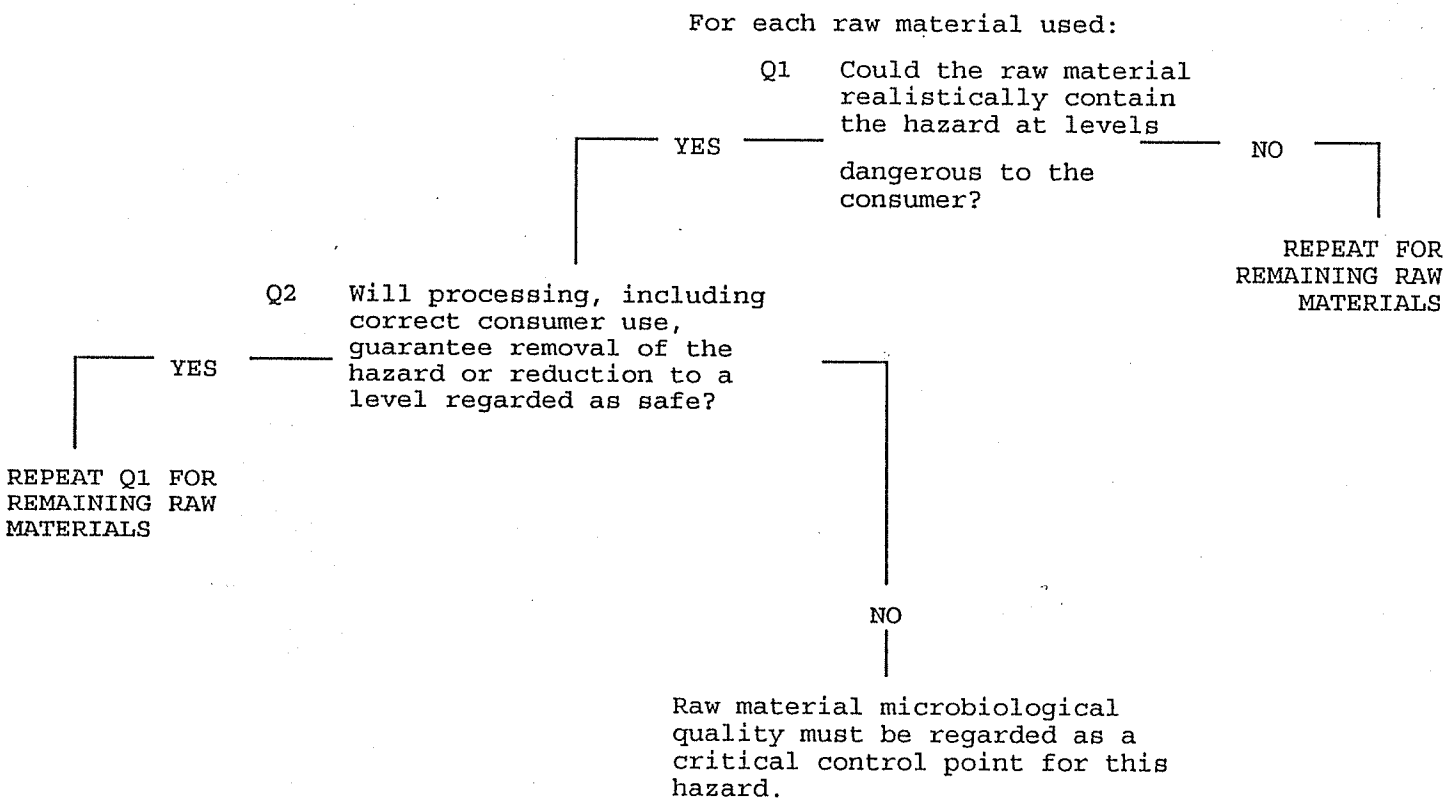

For each raw material used:
Q1
Could the raw material realistically contain the hazard at levels dangerous to the consumer?
YES
NO
REPEAT FOR REMAINING RAW MATERIALS
Q2
Will processing, including correct consumer use, guarantee removal of the hazard or reduction to a level regarded as safe?
YES
REPEAT Q1 FOR REMAINING RAW MATERIALS
NO
Raw material microbiological quality must be regarded as a critical control point for this hazard.

Figure 5. Example of Broiler Barn Log Sheet for monitoring growout conditions and feed withdrawal.

GROWER:	**BARN:**
Barn hygiene check list	Flock history
Litter:	Date stocked:
Water:	Hatchery:
Insect/bird/rodent:	Antibiotics/dates
Feed	
Temp. control:	Other chemicals/dates:
Sanitation:	
Catch date:	Time confirmed
Feed withdrawn @	Signed (Grower)
Loading finished @	Signed (Driver)
Truck #	Kill commenced @

for such a log. Random checks should be made to ensure actual compliance.

Flocks known to be *Salmonella*-positive should be scheduled to be processed last during the shift to reduce the risk of cross-contamination. Ante-mortem inspection to detect sick and dying birds and postmortem inspection to diagnose certain diseased conditions are other critical aspects which require monitoring.

Each step in the evisceration process - vent opening, viscera removal and presentation, and inspection, is a critical control point and requires close monitoring. In addition, the stage at which carcasses with visible fecal contamination are dealt with is also a critical point. As contaminated carcasses are removed from the main line to the salvage or reprocessing station, they must be washed and trimmed promptly. Delays result in increased bacterial attachment and resistance to detachment (Lillard, 1989b). At this point, product handling techniques becomes critical in order to avoid cross-contamination. Important aspects include proper sanitizing of knives, stainless steel mesh gloves, carcass supports, and the direction, pressure and time used for spray washing. Whether parts are salvaged or whole carcasses reprocessed, monitoring and re-inspection must be thorough to avoid cross-contamination during further processes such as chilling, boning, grinding or packing.

2.19.iii Establish Critical Limits

Critical limits are values which separate acceptability from unacceptability, and will at least meet government regulations, plant standards or other scientifically determined norms. These may vary from zero tolerance for failure at reinspection of reprocessed carcasses to range between minima and maxima for feed withdrawal times. The parameters relevant to the five CCPs are recorded on Table 9.

2.19.iv Monitoring Procedures

Monitoring is a planned sequence of observations or measurements which help assess whether a CCP is under control and it is used to facilitate accurate record keeping. In-plant records or procedures are identified in the appropriate column in Table 9. It is important that the monitoring procedure be performed conscientiously, since it reveals if there is a lack of control at a particular CCP.

2.19.v Deviation Procedures

A deviation is a failure to meet the specified critical limits. When this occurs, the predetermined and documented set of corrective actions, i.e., deviation procedures, are implemented. The control measures ensure proper identification and handling of the affected lots so that the potential hazard is avoided. These are shown in Table 9.

TABLE 9. HACCP plan for chilled eviscerated poultry.

PRODUCT: Chilled eviscerated poultry

Process steps	CCP#	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
Feed Withdrawal	CCP:1B	Intestines too full of feed increases risk of rupture and fecal contamination	5 - 6 hrs prior to loading; 8 - 10hrs prior to slaughter	Barn Log Record	Change kill schedule to best suit withdrawal time	Supervisor checks copy of Barn Log before start of kill	Daily Kill & Evisc W/Sheet CCP Action Record
Vent Opening & Evisceration	CCP:2B	Risk of fecal contamination from perforated gut	<4% avg <2.5%	% F/C checked at beginning of each flock; guts and gizzards checked for amt and condition of contents	If auto, ckeck adjustment; if manual, check technique. Correct at salvage/ reprocessing	Supervisor reassesses %F/C	Flock Quality Sheet Daily Kill & Evisc W/sheet CCP Action Record
Viscera Presentation	CCP:3B	as above	Absolute min. due to error	Supervision	as above	as above	as above
Salvage/ Reprocessing	CCP:4B	Risk of missing F/C[1]	Zero tolerance after reinspection	Reinspection of every reprocessed carcass; regular check of parts	Re-reprocess; check technique	Reinspection; Random checks - visual and micro analyses	Daily Kill & Evisc W/sheet; Random Ops Check Sheet
Immersion Chilling	CCP:5B	Risk of excessive bacterial growth if temp/time/water not optimum	Min. 2L/carcass Constant o/flow <5°C carcass internal temp.	1/2 hr temp checks Daily maintenance/ performance checks Regular o/flow checks	Check o/flows Check transfer pump Check make-up rate Add ice Stop discharge Ice last birds	Supervisor checks monitoring procedures Daily random ckecks Random micro analyses	as above + Maintenance/ performance record.

[1]F/C = Fecal contamination

2.19.vi Verification Procedures

Verification procedures are checks and tests which confirm the validity and effectiveness of the HACCP plan. They may involve analytical testing or auditing of the monitoring procedures, product sampling, record audits or plant inspections.

2.19.vii Establish HACCP Records

The HACCP records are the in-plant recording for each CCP which ensures the HACCP plan is followed. The worksheets, etc., relevant for each CCP are listed in the last column in Table 9. An example is given in Fig. 6, which is a CCP Action Record providing a historical record of the process, the monitoring, the deviations and corrective actions, and verification of restored control. This will reveal consistent problem areas which management should address.

Figure 6. HACCP plan for recording problems, action and verification at CCPs.

CCP ACTION SHEET								
PROBLEM			CORRECTIVE ACTION			VERIFICATION		
TIME	CCP#	DETAILS	DETAILS	TIME	SIGN'D	DETAILS	TIME	SIGN'D

CCP# 1 = Feed withdrawal
2 = Vent opening & evisceration
3 = Viscera presentation
4 = salvage/reprocessing
5 = Immersion chiller

3. PAPER 1

An Investigation of Microbial and Hydraulic Aspects of Immersion Chilling of Poultry.

3.10 ABSTRACT

Per capita consumption of poultry in Canada increased between 1982 and 1992 by 33% to 23.1Kg. This trend is likely to continue in the future so that processors will require efficient and informed control of all aspects of their operation. Hazard analysis critical control point programs are widely being implemented and identify immersion chilling of carcasses as a major critical control point. A study was undertaken to investigate the microbial and hydraulic aspects of a two-unit chiller within a small to medium commercial slaughter establishment. Fifty pre- and post-chill carcasses were sampled over a ten day period to establish baseline standard plate counts (SPC) and coliform counts. Counts ($\log_{10}$ CFU/mL) for SPC were 4.70 and 3.74; and coliform counts were 3.99 and 3.03 respectively. Pre-chiller and chiller waters were also sampled, yielding SPCs of 4.43 and 3.53; the coliform counts were 3.40 and 3.03 respectively. There was no significant difference ($p<0.0001$) in pre- or post-chill carcass counts with 50% flow rate at the inside/outside (I/O) washer compared to baseline counts. Results of ten consecutive whole carcass rinses and neck-skin maceration confirmed the 1 log reduction in counts due to the washing action of the chiller. Hourly sampling of post-chill carcasses throughout

production over five days yielded microbial counts which remained within baseline parameters. This occurred after the first hour of daily processing. Changes in chiller water turbidity with different make-up rates is illustrated. Results overall imply that pre-chill carcass counts could be reduced by >1 log, by more efficient use of the I/O wash water volumes. Also, that significant reductions should similarly be possible if chiller make-up water could be used first on post-chill carcasses. Immersion chilling not only chilled carcasses rapidly but also reduced the microbial counts on the carcasses by ca. 1 log.

3.11 Introduction

Consumption of poultry products has continued to increase during recent decades. Worldwide, the increase has been 6% during the last 30 years (Mulder, 1993). In Canada, between 1982 and 1992, there was a 33% rise in the *per capita* consumption of poultry meat from 17.3 to 23.1Kg (CCMA, 1993).

To help maintain and improve the popularity of poultry products, processors must continue to ensure a supply which is as microbiologically sound as current available processing methods allow while maintaining a profitable operation. Hazard analysis critical control point (HACCP) programs are universally being implemented throughout the food industry, including poultry, toward this end (Dean, 1990; Anon., 1992; Bristol, 1992). The chilling process, which consists of immersing unshackled carcasses in agitated, flowing, ice-cold water in large, open tanks, is recognized as the major critical control point (CCP) (Simonsen, 1989; Tompkin, 1990; Varnam and Evans, 1991; Tsai *et al.*, 1992). A CCP is any procedure at which control can be applied and a food safety hazard can be prevented, eliminated or reduced to an acceptable level (Agriculture Canada, 1993).

Factors which influence the effectiveness of poultry

immersion chilling must address reduction of both the carcass temperature and microbial load. These include line speed, pre-chill microbial load, hydraulic retention within the chill system and the capacity of the refrigeration system.

Immersion chilling as commonly practised by the poultry industry has often come under scrutiny because of the potential for cross-contamination (Mead and Thomas, 1973; Lillard, 1990; James *et al.* 1992c; and Mead *et al.* 1993). May (1974), however, identified numerous points apart from chilling as other sources of potential cross-contamination, including most equipment, bird to bird contact, air and employees' and inspectors' hands. The findings of most investigators indicate that there is a potential for cross-contamination, but that with properly controlled equipment and adequate water replacement, the washing effect of commercial immersion chilling of broilers will reduce bacterial counts (Bailey *et al.*, 1987). In a survey of five plants in the United Kingdom by Mead *et al.* (1993), only the two using immersion chilling showed a reduction in the carcass count through the chill system. Where air (4hr) or air-blast (1hr) chilling was used, total viable counts either increased slightly or remained the same as pre-chill counts.

The purpose of the present study was to determine the influence of the chilling process in a small commercial plant on the carcass microbial load. Included in this were the

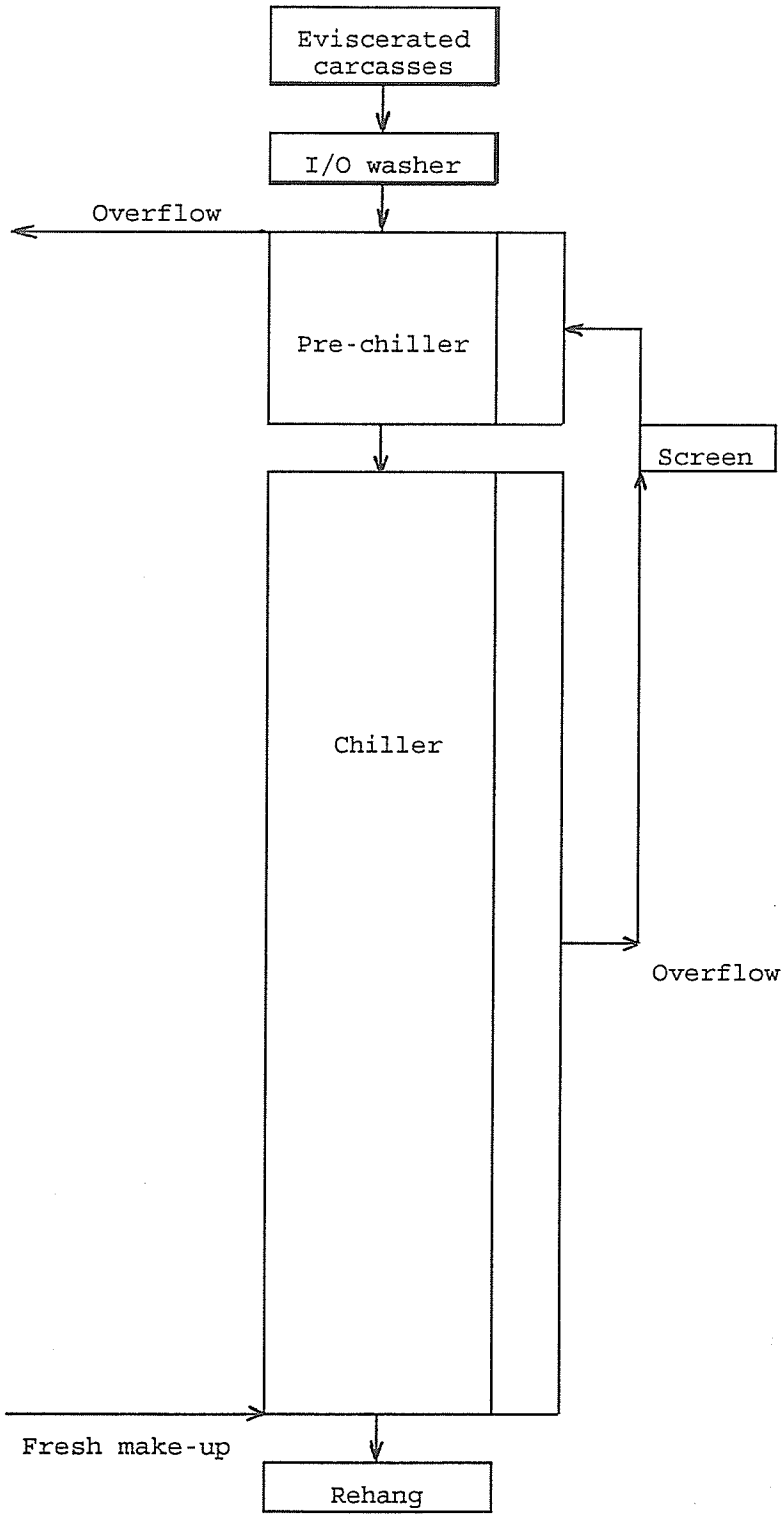
changes in water and carcass counts due to time of day and rate of make-up water addition; and the effect of reducing the flow rate in the inside/outside (I/O) washer.

3.12 Materials and Methods

The process: Figure 1 shows the flow diagram for the washing and chilling stages. Broiler carcasses were eviscerated at a line speed of 72 birds/min, passed through an I/O washer, and dropped from their shackles into a pre-chill tank (4000L). Residence time in the pre-chiller was less than 5min after which they were discharged into the spin-chiller (22,000L) where they were retained for about 25 - 40min. Agitation in both tanks was by means of horizontal paddles. Water from the return troughs was directed back through the tanks in the same direction as the carcasses. Fresh make-up water was added to the spin-chiller and the overflow screened and pumped as make-up to the pre-chiller. This was to compensate the system for moisture pick-up and drip losses with exiting carcasses, and to help meet the requirement of a minimum 2L/carcass. Overflow from the pre-chiller discharged to the gut flume.

Baseline survey: A baseline microbial status was established by sampling before and after chilling. Ten carcasses were sampled, five before the pre-chiller and 5 after the chiller, on each of ten days. Standard plate counts (SPC) and coliform

Figure 1. Flow diagram of immersion chiller arrangement for broilers.


Eviscerated carcasses
I/O washer
Overflow
Pre-chiller
Screen
Chiller
Overflow
Fresh make-up
Rehang

counts were determined for carcasses and pre-chiller and chiller waters. Turbidity measurements were also made on the waters. All samples were taken out between 10:00 and 10:30 am.

Time-of-day and water make-up rate effects: Hourly carcass and water samples were taken during each of five days for determination of SPC, coliforms and turbidity. Make-up rates were 20, 30, 35 and 50 (days 4 and 5) L/min.

Effect of 50% reduction of I/O flow rate: Ten carcasses were sampled, five after the I/O washer (before the pre-chiller) and five after the chiller, on each of 3 days with the flow rate controlled back to 45 L/min.

Sampling: Pre-chill samples were taken at random after the I/O washer and before entry to the pre-chill tank. Post-chill samples were taken as the carcasses exited the spin chill tank before manual rehanging. A whole bird rinse, consisting of 100 mL of sterile 0.85% saline in a sterile bag (31 x 62 cm) was used. The bag was twisted at its midpoint to form a "balloon" with the carcass free to move inside. The bag and contents were shaken for 30 s after which the rinse was poured back into its bottle and stored in ice for transport to the laboratory. Analyses were commenced within three hours of sampling.

Two tests to confirm the change in carcass microbial load as a result of immersion chilling were performed. These consisted of **(a) multiple rinses** on pre- and post-chill

carcasses: One carcass sampled before the pre-chiller and one after the chiller were each subjected to ten consecutive whole carcass rinses; and **(b) maceration of skin samples:** 25 g of neck skin from one pre-chill and one post-chill carcass were each macerated in a blender with 225 mL 0.1% peptone for 60 s.

Microbiological sampling: Rinse samples from carcasses and chiller water samples were serially diluted using 0.1% sterile peptone solution and evaluated for SPC on Standard Methods agar (BBL; 35°C for 48 ± 2 h). Total coliforms were enumerated on Violet Red Bile agar (BBL; 35°C for 24 ± 2 h) with an agar overlay. Duplicate plate counts were performed in each case. Counts were expressed as $\log_{10}$ colony forming units (CFU) per mL of rinse.

Turbidity: Turbidity readings were made using a Model DRT 100 Turbidity Meter (Fisher Instruments Ltd, Bolton, Ontario) and reported as Jackson Turbidity Units (JTU).

Make-up rate: Mains supply potable make-up water was added to the chill tank (Fig. 1), and the rate controlled by means of a gate valve and an in-line flow meter. All rates were confirmed by measurement.

Hydraulic retention: The hydraulic retention of the chiller system is a measure of the average time the initial charge of water is retained, and is calculated by dividing the initial volume by the make-up (or replacement) rate. This value is an approximation, since the chiller water is being removed not

only by displacement with fresh make-up water but also by moisture pick-up and drip losses with chilled carcasses.

Statistical Analysis: Results were converted to $\log_{10}$ and statistically analysed using the Student's *t*-test (variances unequal; Fig.P Software Corporation, USA).

3.13 Results

Baseline sampling resulted in mean carcass rinse counts ($\log_{10}$/mL) which were approximately 1 log lower for post-chill as compared to pre-chill carcasses (Table 1 and Fig. 2). Results of neck skin maceration and consecutive whole carcass rinses also supported this finding (Table 2). There was also a 1 log difference in the SPC for pre-chill water and chiller water.

Results of hourly sampling throughout each of five days are illustrated in Figs. 3 and 4. Post-chill carcass counts tended to level off after the first one to two hours, while water turbidity readings and bacterial counts continued to increase to a greater or lesser degree depending on the rate of addition of fresh make-up water. Days 4 and 5 are combined in Fig. 4 and the average shown, since the make-up rate was the same on both days (50 L/min).

Reducing the volume of water per carcass used in the I/O washer was shown to have no effect on microbial counts based

TABLE 1. Summary of (log_{10} CFU/mL) SPC and coliform counts on pre- and post-chill carcasses for baseline study and with reduced flow at the I/O washer, and in baseline chiller waters.

		Mean count[1] (log_{10}/mL)	
Sample	n	SPC	Coliforms
Baseline[2]			
Pre-chill carcasses	50	4.70 ± 0.34[a]	3.99 ± 0.62[a]
Post-chill carcasses	50	3.74 ± 0.32[b]	3.03 ± 0.25[b]
Pre-chiller water	10	4.43 ± 0.48[c]	3.40 ± 0.42[c]
Chiller water	10	3.53 ± 0.41[d]	3.03 ± 0.14[d]
With I/O @ 50% flow rate[3]			
Pre-chill carcasses	15	4.78 ± 0.34[a]	3.97 ± 0.40[a]
Post-chill carcasses	15	3.71 ± 0.27[b]	3.02 ± 0.21[b]

[1]Mean count ± std. dev.
[2]Baseline samples taken at 10:30am. and with the I/O washer at 90L/m.
[3]Reduced flow maintained throughout the shift and samples taken at the end (approx. 2:30pm.)
[ab]Carcass mean counts followed by different superscripts within columns are significantly different ($p<0.0001$).
[cd]Water mean counts followed by different superscripts within columns are significantly different ($p<0.005$)

Figure 2. Daily means (± std. dev.) of baseline SPC and coliform counts for pre- and post-chill carcasses.

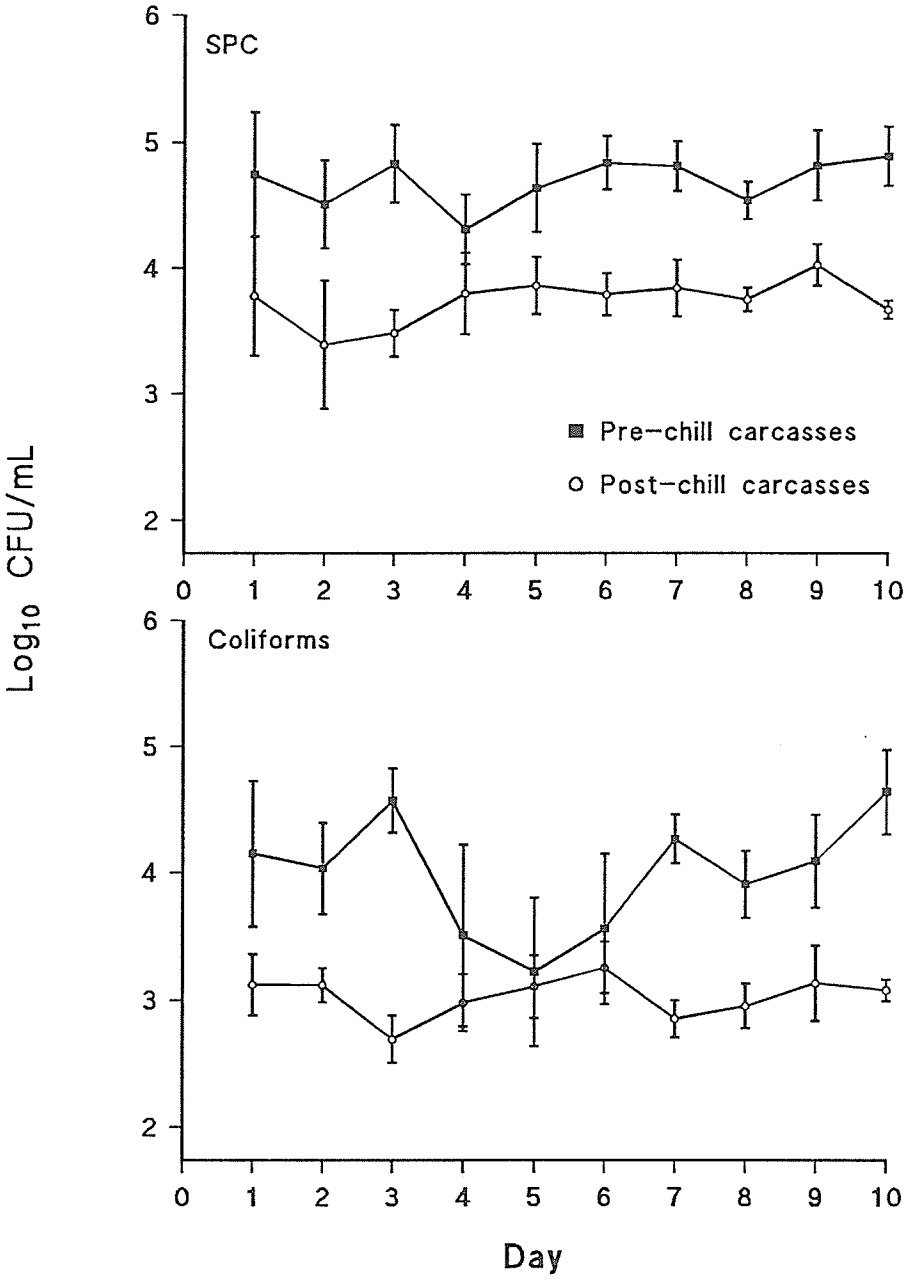

SPC
Coliforms
Pre-chill carcasses
Post-chill carcasses
Log10 CFU/mL
Day
0
1
2
3
4
5
6
7
8
9
10
2
3
4
5
6

TABLE 2. Summary of results of confirmatory tests for effect of immersion chilling on broiler carcasses.

Sample		Whole carcass rinse (log_{10} CFU/mL)		Skin maceration (log_{10} CFU/g)	
		SPC	Coliforms	SPC	Coliforms
Initial count	- before chiller	4.40	4.27	5.00	4.47
	after chiller	3.18	2.82	4.00	3.56
10th rinse	- before chiller	3.10	2.65	3.60*	2.65*
	after chiller	2.72	2.05	2.74*	2.27*
$\sum$ 10 rinses	- before chiller	4.72	4.51	-	-
	after chiller	3.85	3.37	-	-

*skin maceration performed after the 10th consecutive rinse.

Figure 3. Mean (log_{10} CFU/mL) SPC and coliform counts as a function of time-of-day for chiller water and post-chill carcasses.

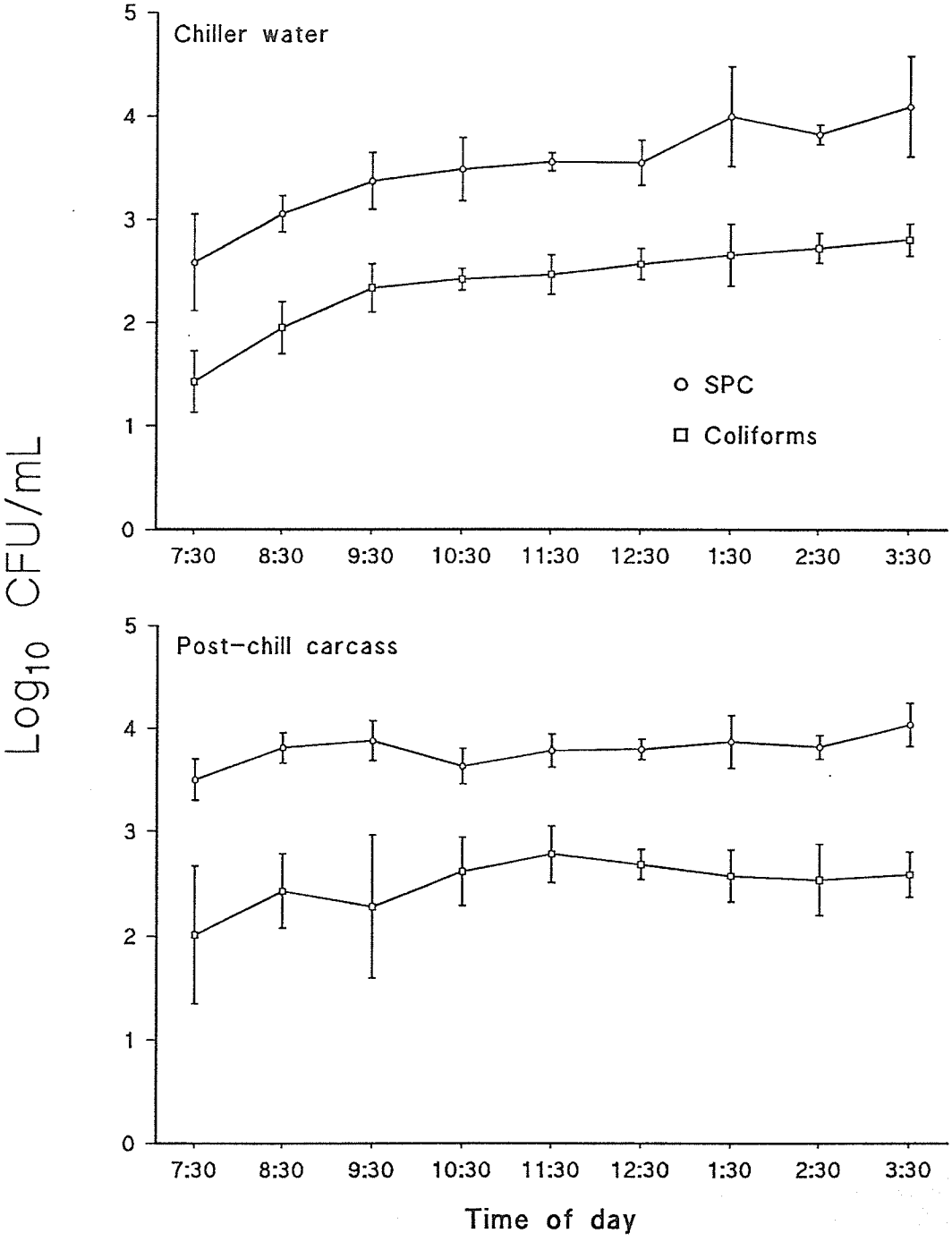
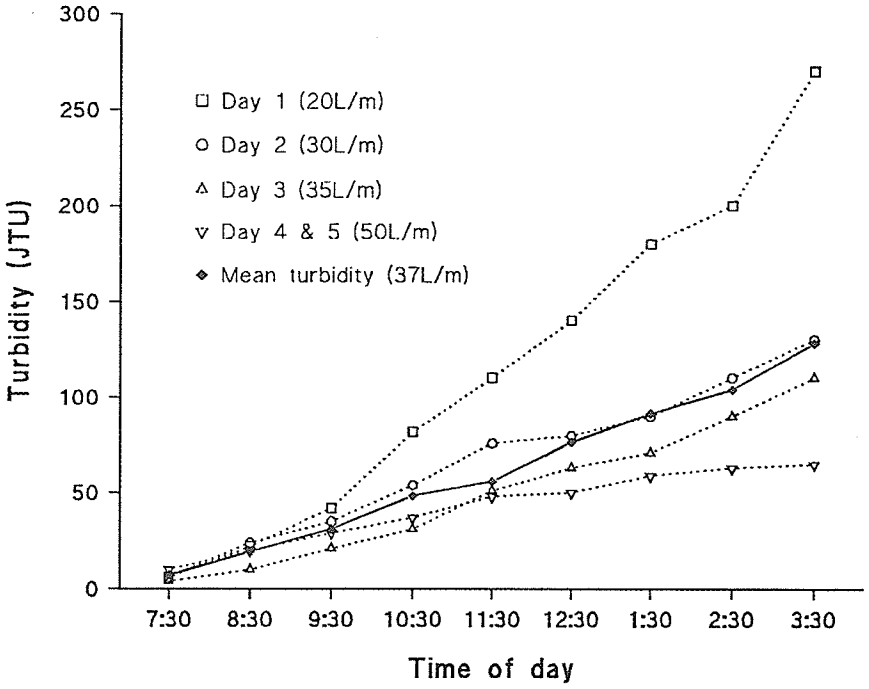

Chiller water
Post-chill carcass
SPC
Coliforms
Log10 CFU/mL
Time of day
0
1
2
3
4
5
7:30
8:30
9:30
10:30
11:30
12:30
1:30
2:30
3:30

Figure 4. Effect of time-of-day and make-up rate on chiller water turbidity.


300
250
200
150
100
50
0
Turbidity (JTU)
Day 1 (20L/m)
Day 2 (30L/m)
Day 3 (35L/m)
Day 4 & 5 (50L/m)
Mean turbidity (37L/m)
7:30
8:30
9:30
10:30
11:30
12:30
1:30
2:30
3:30
Time of day

on whole carcass rinse sampling (Table 1). Bacteria were consistently removed from carcasses at levels of >100 CFU/mL with consecutive whole carcass rinses; even up to the tenth rinse (Fig. 5).

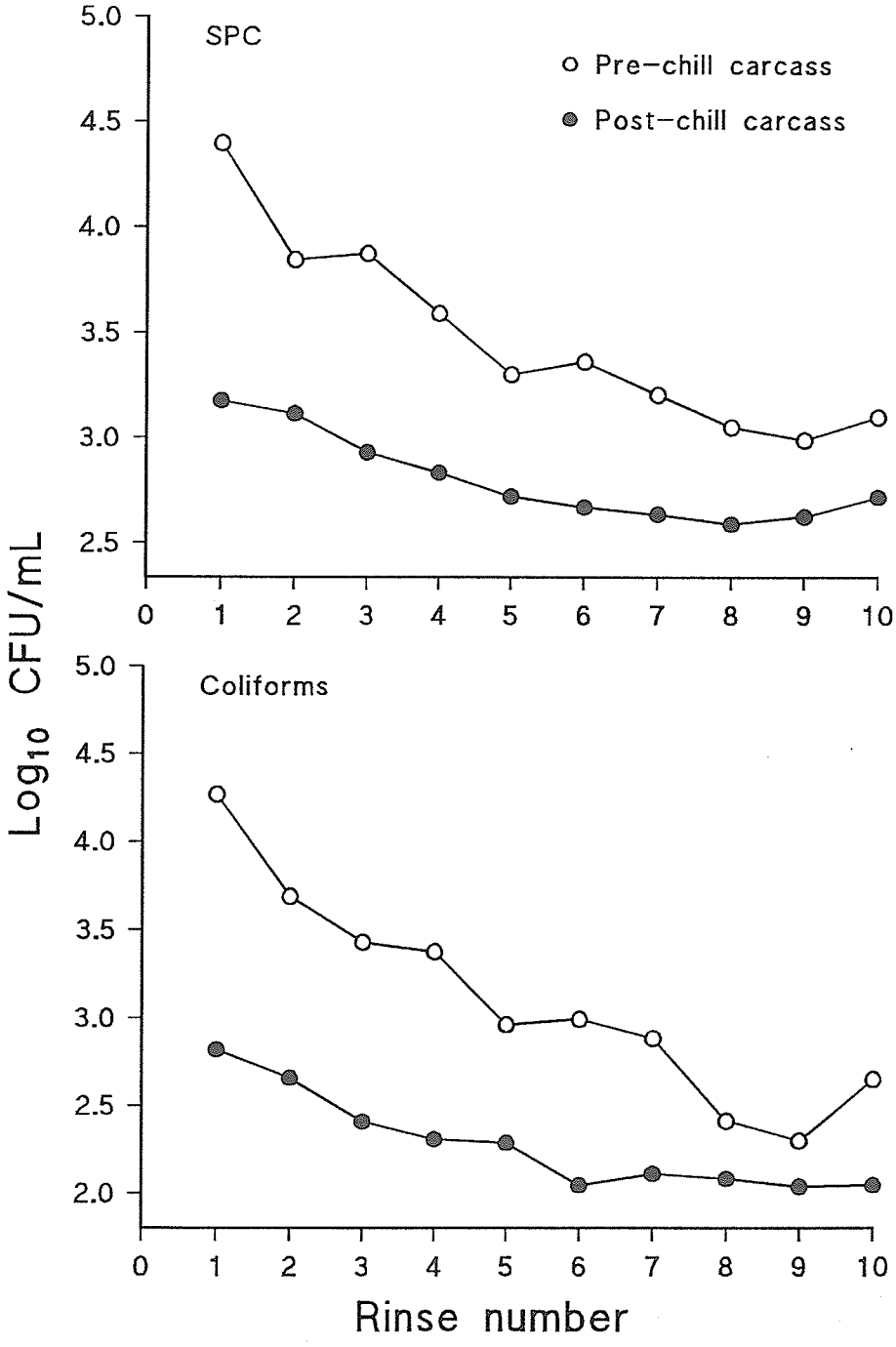
3.14 Discussion

The washing effect of immersion chilling has been shown to reduce both coliform and total viable counts on poultry carcasses by up to 98% (Surkiewicz *et al.*, 1969; Vacinek, 1972; Mead and Thomas, 1972; May, 1974; Lillard, 1990, James *et al.*, 1992c; and Mead *et al.*, 1993). In the present study, the end-of-shift post-chill carcass count (Table 1) represented a >90% reduction in SPC compared to the mean count for pre-chill carcasses, despite an average increase to more than 6,000 CFU/mL in the chiller water through the day. Baseline carcass counts obtained at 10:30 am were also found to be similar to those at the end of the shift.

Chilled water counts appeared to correlate with turbidity readings for both the chiller (Figs. 3 and 4) and the pre-chiller (data not shown). This would indicate a possible quick and simple test to use as a guide for monitoring chiller control.

Calculations based on the data summarized in Table 2, showed that the count obtained from the initial post-chill

Figure 5. The effect of consecutive whole carcass rinses on the microbial level of pre- and post-chill poultry carcasses.


SPC
Pre-chill carcass
Post-chill carcass
Coliforms
Log10 CFU/mL
Rinse number
5.0
4.5
4.0
3.5
3.0
2.5
2.0
0
1
2
3
4
5
6
7
8
9
10

carcass rinse was only 21% of the total of ten consecutive rinse counts, and that this in turn, was only a fraction of the total remaining on the carcass - as indicated by the results from skin maceration after the tenth rinse. Lillard (1988 and 1989b) reported similar findings using up to 40 consecutive whole carcass rinses, multiple stomaching of skin samples and blending of skin samples. She also reported that the mean counts obtained from the first whole carcass rinse, the first stomaching and the blending procedure were not significantly different ($p<0.05$). The number of aerobes obtained from the first rinse was 10% of the total obtained from 40 consecutive whole carcass rinses, however, the actual percentage would be negligible if the true total number of bacteria on the carcass could be known (Lillard, 1988).

Assuming negligible growth of organisms in the chiller water during the shift, the only control over their build-up is the rate of fresh water addition. This in turn is influenced by the requirement for not less than 2 L/carcass (weighing 2.5Kg or less) and for sufficient overflow to ensure the removal of extraneous materials (Agriculture Canada, 1982). Regulations have been ammended to allow the inclusion of water used at the I/O washer as part of the 2 L/carcass. This effectively reflected the finding of Wesley (1977) that 50% of the USDA required metered chiller input resulted in no detrimental effects on the quality of the chiller water or

poultry carcasses.

With the system used in the present study, a minimum of 35 L/min. was found necessary just to ensure some overflow from the prechiller. (In practice more was used.) This represented a hydraulic retention for the chilling system as a whole of 686 min., meaning that approximately only half the water would be replaced during the production shift. At that rate also, the minimum 2 L/carcass could only be achieved if the I/O flow were reduced by 50%. However, the actual make-up rate will vary depending on several factors, including the temperature of the water supply (time of year), number and size of birds to be processed, scalder temperature and line speed.

Correct operation of the chiller system can significantly help optimize product yield (Martin, 1993). Greater extraction of fat from the carcasses in the pre-chiller was observed at lower make-up rates to the chiller. The reason for this was that less cold chiller water was overflowed to the pre-chiller, causing its temperature to increase. Martin (1993) recommended monitoring the chiller operation to provide data on its ability to handle environmental changes so that different chiller procedures could be implemented as input variables changed.

Results given in Table 1 indicated a substantial saving in water can be gained at the I/O washer without affecting the

microbial quality of the chilled carcasses. The water saved at this point could be translated to reduced cost of operation, or used for extra pre- or post-evisceration spray washes, or for reprocessing uses. They also imply that the contact time rather than the volume of water at the I/O washer affects bacterial removal. This is also illustrated in
Figure 5. Multiple low-volume whole carcass rinsing resulted in >1.5 log reduction in coliform numbers on pre-chill carcasses and >1 log reduction in SPCs. Future trials could be aimed at replicating these reductions by way of a pre-chill spray cabinet with as many successive spray heads as line space permits.

A final consideration is whether potable make-up water to the chiller could also be used more effectively. The reduction in numbers of bacteria on post-chill carcasses as a result of multiple rinses was less than for pre-chill carcasses (Fig. 5) due to the extra time for attachment and the lower initial numbers. However, if make-up water could first be used on carcasses via a cabinet wash after rehang, it would remove much of the surface film of 10^3 CFU/mL-chiller water. Mead *et al.* (1993) noted the increased proportion of pseudomonads on chilled and packaged carcasses after a decrease at scalding. While the increase was lower on immersion chilled carcasses than air-chilled ones, some removal as suggested above may help improve product shelf-life.

3.15 Conclusion

As the last step of carcass processing, the chilling operation has a direct, profound impact on the safety and quality of the finished products (Tsai *et al.* 1992). The chilling system studied was shown to reduce bacterial counts on carcasses by 1 log, however, this reduction may be very small in relation to the actual numbers remaining. Post-chill whole carcass rinse counts remained within baseline parameters regardless of the time of day and despite a 50% reduction in I/O washer volume. The potential for more effective use of pre-chill wash water and chiller make-up water was apparent and should be further investigated.

4. PAPER 2

Microbiological Comparison of Inspection-Passed and Reprocessed Broiler Carcasses.

4.10 Abstract

Canadian regulations require that chicken carcasses with visible post-evisceration internal contamination be removed from the process line. Such carcasses are condemned after unaffected parts are salvaged by hot-boning. Contamination rates vary from less than 1% to more than 5% with a cost to the industry which may exceed four million dollars annually for each percent contamination. In order to provide additional data with regard to the microbiological safety of reprocessed broiler carcasses, a study was conducted using a cup-rinse sampling method. Contaminated carcasses were reprocessed manually off-line and in a vent-down position by an immediate 5 sec inside/outside (I/O) spray wash followed by vacuuming and a 15 sec I/O spray wash. Potable water at line pressure was used. Average colony forming units (log_{10}/mL) for inspection-passed and reprocessed carcasses included: standard plate count (SPC) 3.99 and 3.55, coliforms 3.49 and 3.07, *Escherichia coli* 3.34 and 2.96 and *Staphylococcus* 2.42 and 1.53 respectively. The detection frequencies for *Salmonella* and *Campylobacter* were 4 and 5% and 84 and 74% respectively. Light and gross contaminated carcasses were distinguished visually and evaluated for SPC, coliform and *E.*

coli before any wash treatment. Carcasses identified as being gross contaminated showed lower average counts than inspection-passed carcasses following reprocessing. A comparison study using a whole carcass rinse method, including re-inspection, confirmed the efficacy of the reprocessing treatment to successfully restore condemned carcasses to the same or better microbiological status as inspection-passed carcasses.

4.11 Introduction

In 1992, over 360 million broilers were processed in Canada (Agriculture Canada, 1993). In addition, approximately 1 to 5 per cent were condemned following routine visual inspection by government officials for intestinal contamination. Current Agriculture Canada regulations allow salvaging of unaffected parts; in addition, any contamination on cut surfaces must be removed by trimming or may be thoroughly washed off if present on intact skin surfaces (Agriculture Canada, 1992). Economic losses to the industry due to hot boning of contaminated carcasses may exceed four million dollars annually for each per cent of contamination. While the Canadian government recognizes the economic effect of this requirement and its impact on the international competitiveness of local processors, it has lacked sufficient data to support a change to allow reprocessing viz, the removal of fecal or intestinal contamination due to eviscervation accidents by vacuuming, washing and slight trimming singly or in combination, as necessary, that could otherwise jeopardize public health standards.

In 1978 the USDA allowed contaminated poultry to be reprocessed subsequent to the finding of Blankenship *et al.* (1975). The study reported that when contaminated carcasses received an on-line internal spray wash consisting of 200 ml

water, before passage through the final washer, the bacteriological counts were not significantly different from those of inspection-passed carcasses. Recent studies with regard to the microbiology of reprocessed carcasses (Blankenship *et al.* 1990, Blankenship *et al.* 1993, Waldroup *et al.* 1993) have confirmed earlier findings.

Thiessen (1985) conducted a study in two Canadian processing plants in regards to reprocessing of broiler carcasses. In one plant reprocessed and inspection-passed carcasses were found to be microbiologically similar when total plate and coliform counts were compared. In the other plant reprocessed carcasses exhibited significantly higher total plate and coliform counts. In both plants fewer reprocessed carcasses passed visual examination compared to those which were inspection-passed. Overall the results, failed to support the safety of reprocessing and the regulations have remained unchanged.

The present study, in which preliminary testing and sampling was performed in order to establish a reprocessing protocol which would have a good probability of success, was designed in order to provide additional data with regard to the microbiological quality and or safety of reprocessed broiler carcasses. Carcasses were obtained from a small to medium federally inspected processing plant, that routinely slaughters broilers during a single-day shift at an average

line speed of 72 birds per minute.

4.12 Materials and Methods

Reprocessing protocol. Carcasses with visual internal contamination were identified by a government inspector. An operator cut off the viscera and transferred the carcass to an off-line stand. After manual removal of the trachea, oesophagus and neck, the carcasses were washed (approx. 5 sec.) prior to vacuuming in order to reduce cross contamination by the gun. Following vacuum treatment the carcasses were rewashed (approx. 15 sec.). All washing was performed using a modified inside-outside spray washer.

The inside spray head consisted of a modified nylon fitting obtained from a conventional inside-outside washer. The sprayhead was attached to a nylon extension tube (8.5 cm) along which holes (1.5 mm) were drilled. A stainless steel frame and collar around the sprayhead supported the carcass in a tail-down position. This position was chosen because most of the visible contamination (internal and external) was invariably observed towards the tail end. Therefore during the washing there would be less probability of cross contamination by the rinse over the cleaner tissue. Externally, the carcasses were washed using three fan-sprays, one of which was positioned to rinse the tail area including

the exposed muscle tissue at the vent cut. Each carcass was washed with approx. 6 L of potable water (8-10°C) at a line pressure of 345-380 KPa. No additional chlorination was used.

Carcass sampling. Carcasses were taken within the first two hours of morning start-up which invariably ensured that the first flock was sampled. The sampling procedure entailed the use of commercial, disposable plastic cups (200 ml capacity; 83 x 75 mm) containing 100 ml sterile peptone (.1%) plus 1% Tween 80 (PT). The carcass was positioned over the cup such that the tail was immersed in the rinse water and a tight seal was formed. While gripping the carcass across the back just below the wings with one hand and holding the cup firmly in place over the vent opening with the other hand, the carcass and cup were shaken together for 30 sec (7 to 8 sec clockwise, 7 to 8 sec anticlockwise) first vertically then horizontally. The rinse water was allowed to drain back into the cup and the contents were transferred back into sterile bottles. Bottles were stored in ice for transport; all analyses were performed within three hours of sampling.

Microbial comparison of inspection-passed and condemned (contaminated) carcasses before washing or processing. Based on a subjective assessment of the contamination level in the body cavity and/or on or surrounding the vent opening, light and gross contaminated carcasses were identified visually as they were inspected off the line. Once the trachea and

oesophagus were removed, the carcasses were sampled using the cup-rinse method. These carcasses received no wash or vacuum treatment prior to sampling. Inspection-passed carcasses were removed from the line between the trachea - oesophagus removal and vacuuming and were similarly sampled. Five carcasses from each group were evaluated on each sampling day.

Microbial comparison of inspection-passed (washed) and reprocessed carcasses using the cup rinse method. Carcasses were randomly selected for reprocessing as they were inspected off the line and identified as either light or gross. Reprocessed carcasses were sampled immediately following the reprocessing procedure (inside-outside wash). Inspection-passed carcasses were randomly sampled immediately after exiting the inside-outside washer (prior to entering the chiller). Six carcasses from each group were evaluated on each sampling day. Of the carcasses selected for reprocessing, on all but two days, half were identified as being gross contaminated.

Microbial comparison of inspection-passed (washed) and reprocessed carcasses using a whole bird rinse method. The protocol used was similar to that described above except that a whole bird rinse method was used. The rinse (100 ml of PT) was added to each carcass contained in a sterile bag (31 x 62 cm). The bag was twisted at its mid-point to form a balloon with the carcass free to move inside. The carcass was shaken

by hand for 30 sec. Approx. six carcasses from each group were evaluated on each sampling day.

Microbiological Analyses

Rinse samples from the carcasses were serially diluted using PT and evaluated for standard plate counts using standard methods agar (BBL; 35°C for 48 ± 2 h). All values were reported as the averages of duplicate plate counts.

Total coliforms and *Escherichia coli* were enumerated using a hydrophobic grid membrane filter (HGMF, 0.45-μm; ISO GRID®; QA Laboratories Ltd, 1989) technique according to Entis (1989). Aliquots of rinse sample (1.0 ml) diluted using PT if necessary, and without enzyme pretreatment were filtered through an ISO GRID® system. The filters were aseptically removed and placed, grid side-up, on the surface of pre-poured solified plates of lactose monensin glucuronate agar (QA Laboratories) and incubated at 35°C for 24 ± 2 h. All grid cells with blue or blue shaded colonies were counted. Membranes showing typical colony growth were then transferred to pre-poured solidified plates of buffered 4-methylumbelliferyl β-d-glucuronide (MUG) agar (QA Laboratories) and incubated for a further 2 h at 35°C. *E. coli* was enumerated by placing the membranes under longwave UV light and counting all grid cells exhibiting fluorescence. The most probable number (MPN) was calculated for both total

coliform and *E. coli* using the average most probable number growth unit (MPNGU) of duplicate samples (QA Laboratories Ltd, 1989).

Salmonella was also detected using the HGMF technique (Entis and Boleszczuk, 1991; QA Laboratories Ltd, 1989). Samples (25 ml) were preenriched in lactose broth (225 ml; Difco) for 20 - 24 h at 35°C. For selective enrichment, 0.1 ml of the preenrichment culture was inoculated into 10 ml of tetrathionate brilliant green broth (TBGB, QA Laboratories) vortexed and incubated at 35°C for 6 - 8 h in a water bath. Following incubation 1.0 ml of a 10^{-2} dilution was membrane filtered; the membrane was transferred to pre-poured solidified plates of EF-18 agar (QA Laboratories) and incubated at 42°C for 24 ± 2 h. The filters were examined for the presence of presumptive positive colonies (green or blue/green shaded colonies) and when possible up to three such colonies were subcultured to triple sugar iron agar (BBL) lysine iron agar (BBL) and MacConkey agar (BBL, 18 - 24 h; 35°C). Presumptive cultures showing typical reactions were confirmed using biochemical tests (API 20E; API Laboratory Products Ltd, St. Laurent, Quebec) and slide agglutination (Difco). Serotyping was performed by Cadham Provincial Laboratory (Winnipeg, Manitoba).

Campylobacter was detected by inoculating 20 ml of Preston enrichment broth with 5 ml of rinse samples (Park,

1992). Incubation was carried out at 35°C for 3 to 4 h, and then at 42°C for 24-48 h under microaerobic conditions. A microaerobic atmosphere was achieved by drawing a vacuum in the incubator to approx. 580-610 mm Hg and introducing a mixture of 5% O_2, 10% CO_2 and 85% N_2 from a gas cylinder. Two loopfuls of enriched culture were each streaked onto Preston agar and *Campylobacter* blood-free selective agar (Oxoid) and incubated at 42°C for 48 h under microaerobic conditions. Cultures were examined for catalase and oxidase activity and for motility using phase contrast microscopy. Suspects were subcultured in *Brucella* semi-solid medium containing neutral red under aerobic conditions at 35°C for 24-48 h. and were confirmed by Cadham Provincial Laboratory (Winnipeg, Manitoba). *C. jejuni* was distinguished from other *Campylobacters* by hippurate hydrolysis (Lior, 1984). Staphylococci were enumerated on Baird-Parker agar (BBL) containing egg yolk tellurite enrichment (Difco) using a surface plating procedure (American Public Health Association, 1992). Typical colonies were counted after incubation at 35-37°C for 30 and 48 h. When present, up to five typical colonies per sample were evaluated for coagulase production (American Public Health Association, 1992).

Statistical Analysis

Results were converted to Log_{10} and statistically analyzed using the student's *t*-test for differences of means (variances

unequal; Fig. P Software Corporation, USA). For three-way comparisons the experiment-wise error was maintained at 5% by taking one-third of 0.05 (0.0167) as the comparison-wise error limit for significance. The χ^2 test was applied to the detection frequencies of *Salmonella* and *Campylobacter*.

4.13 Results

The SPC levels for the gross and total contaminated carcasses were significantly higher as compared to those which were inspection-passed (Table 1). Light contaminated and inspection passed carcasses, however, exhibited no significant difference. Similar findings were obtained with coliforms and *Escherichia coli*. The total SPC, coliform and *E. coli* levels in contaminated carcasses were approx. one log higher compared to inspection-passed carcasses. The incidence of *Salmonella* in light and gross contaminated carcasses appeared similar. Overall the incidence of *Salmonella* in contaminated carcasses was not significantly higher compared to those which were inspection-passed. In the case of *Campylobacter*, the frequency of detection was about three and nine times higher than for *Salmonella* in contaminated and inspection passed carcasses respectively. No significant difference was observed between inspection-passed and contaminated carcasses in regards to the incidence of *Campylobacter*. The incidence

TABLE 1. Microbial comparison of inspection passed and contaminated carcasses before either washing or reprocessing.

Organism	Inspection passed	Contaminated		
		Light	Gross	Total
SPC	[a]4.26±0.58	4.60±0.69	5.86±1.13*	5.23±1.13*
Coliform	3.82±0.56	4.19±0.76	5.28±1.11*	4.74±1.09*
E. coli	3.63±0.59	3.99±0.73	5.08±1.16*	4.54±1.11*
Salmonella	[b]9% (3/33)	25% (8/32)	27% (8/30)	26% (16/62)
Campylobacter	85% (17/20)	95% (19/20)	95% (19/20)	95% (38/40)

[a]Means (log_{10} CFU/ml) ± SD; N = 25. For Total contaminated N = 50
[b]Per cent positive
*Significant at $P<0.05$ for comparison with inspection-passed

of *Campylobacter* between light and gross contaminated carcasses was not significantly different. Frequency distributions for SPC, coliforms and *E. coli* are presented in Fig. 1. With the inspection-passed carcasses approx. fifty percent exhibited SPC and coliform levels of 10^4 and 10^5 colony forming units (CFU)/ml respectively. Approximately forty-five percent contained *E. coli* levels of 10^3 CFU/ml. In examining the total number of contaminated carcasses, the majority contained SPC, coliform and *E. coli* levels of 10^4, 10^4 and 10^3 CFU/ml respectively. Only gross contaminated carcasses exhibited microbial levels at 10^6 CFU/ml. Carcasses, including those identified as being gross contaminated, which were subjected to reprocessing contained significantly lower SPC, coliform, *E. coli* and *Staphylococcus aureus* levels when compared to inspection-passed carcasses (Table 2). The incidence level of either *Salmonella* or *Campylobacter*, however, was not significantly different between carcass treatments. The incidence level of *Campylobacter* in reprocessed and inspection-passed carcasses was about 15 to 20 times higher than for *Salmonella*.

The majority of both inspection-passed and reprocessed gross contaminated carcasses contained SPC, coliform and *E. coli* levels of 10^3 CFU/ml (Fig. 2). For *Staphylococcus*, the majority of both groups of carcasses peaked at levels at 10^2 and 10^1 CFU/ml respectively.

Figure 1. Frequency distributions of SPC, coliforms and *E. coli* (log_{10} CFU/mL) for inspection-passed, light, gross and total contaminated carcasses before any wash treatment.

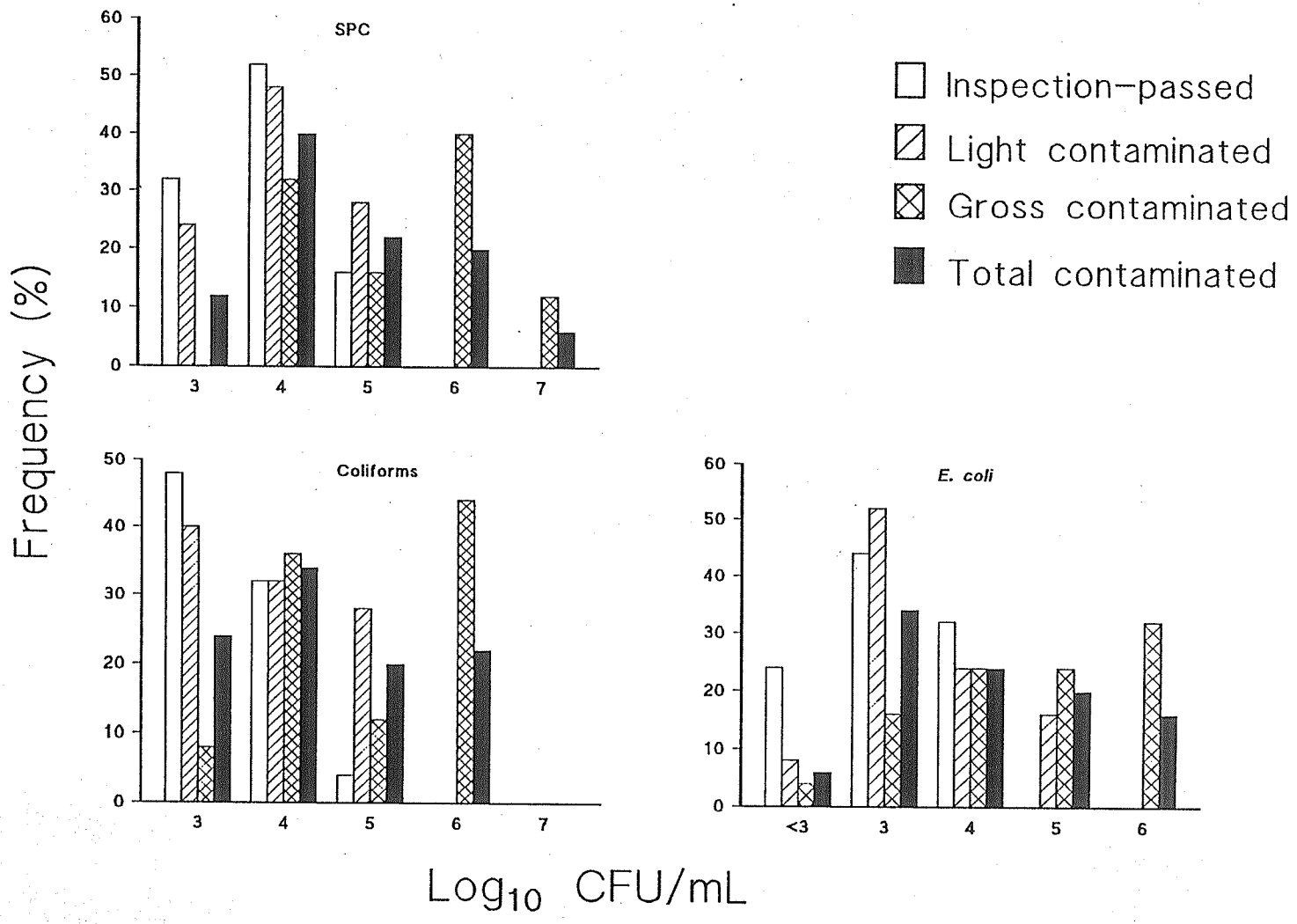
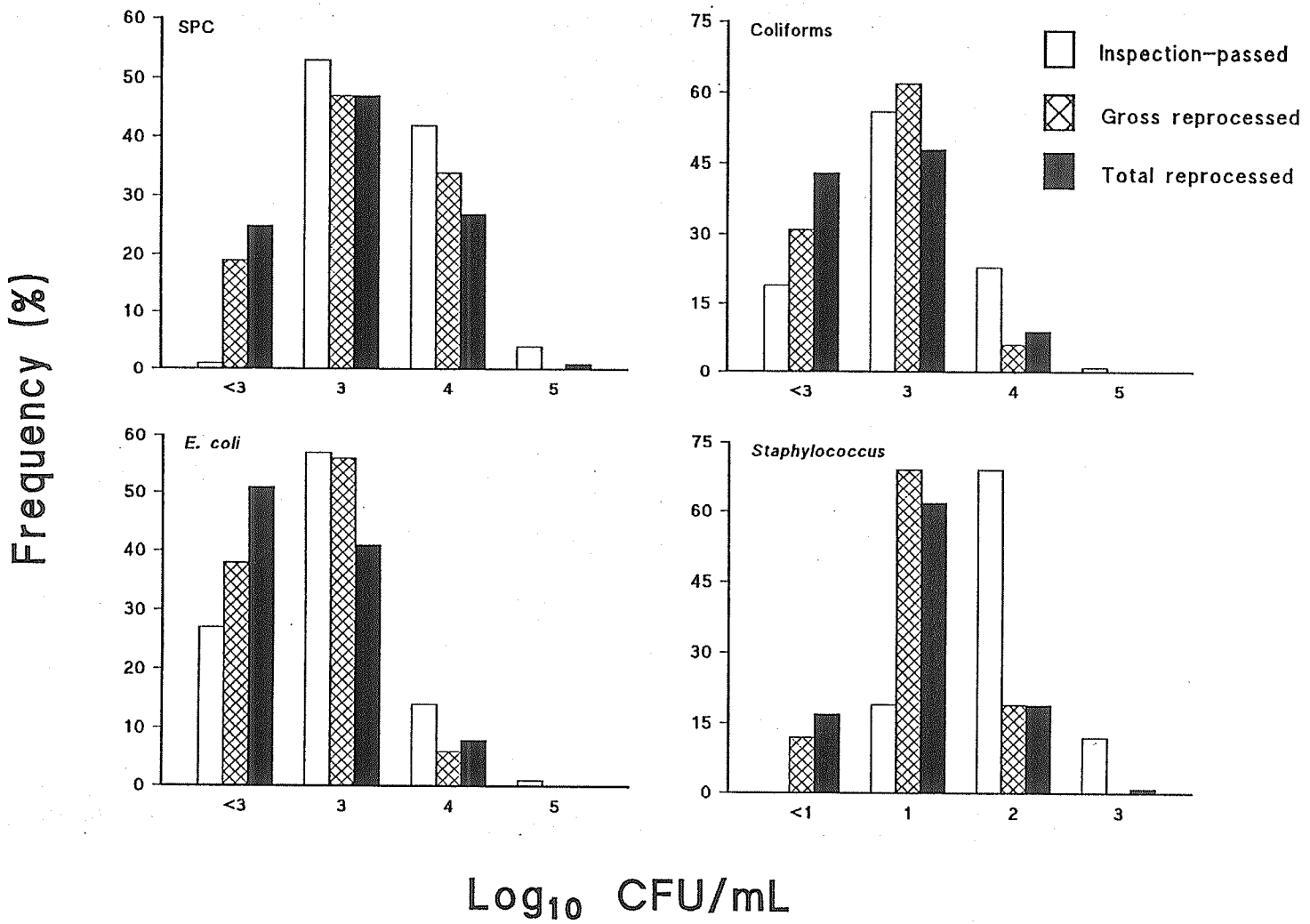

SPC
Coliforms
E. coli
Inspection–passed
Light contaminated
Gross contaminated
Total contaminated
Frequency (%)
Log10 CFU/mL
<3
3
4
5
6
7

TABLE 2. Microbial comparison of inspection passed (washed) and reprocessed carcasses sampled by a cup rinse method.

Organism	Inspection passed	Reprocessed	
		Gross	Total
SPC	[a]3.99±0.54	[b]3.66±0.64*	3.53±0.70*
Coliform	3.49±0.65	3.21±0.70	3.07±0.73*
E. coli	3.34±0.62	3.06±0.61*	2.96±0.67*
Staphylococcus	2.42±0.54	1.51±0.47*	1.53±0.54*
Salmonella	[c]4% (3/77)	0% (0/32)	5% (4/77)
Campylobacter	84% (65/77)	77% (25/32)	74% (57/77)

[a]Means ($\log_{10}$ CFU/ml) ±SD; N=77 for inspection passed and total reprocessed
[b]N = 32, subsample of total reprocessed
[c]Percent positive
*Significant at $P<0.05$ for comparison with inspection-passed

Figure 2. Frequency distributions of SPC, coliforms, *E. Coli* and *Staphylococcus* (log_{10}CFU/mL) for inspection-passed, total reprocessed and gross reprocessed carcasses.


SPC
Coliforms
E. coli
Staphylococcus
Inspection–passed
Gross reprocessed
Total reprocessed
Frequency (%)
Log10 CFU/mL
60
50
40
30
20
10
0
75
45
15
<3
3
4
5
<1
1
2
3

When reprocessed carcasses were sampled using a whole bird rinse method, significantly lower SPC, coliform and *E. coli* levels were also obtained as compared to inspection-passed carcasses (Table 3). However, no significant difference in the level of these organisms was observed among total, gross and light reprocessed carcasses. The incidence of *Salmonella*, although lower in reprocessed carcasses was not significantly different from those which were inspection passed. Only 3 of 50 reprocessed carcasses required further attention following re-inspection (2 with one speck each and 1 with fecal staining). The majority of inspection passed carcasses contained SPC, coliform and *E. coli* levels of 10^4, 10^4 and 10^3 CFU/ml respectively (Fig. 3). These levels decreased to 10^3 CFU/ml for reprocessed carcasses.

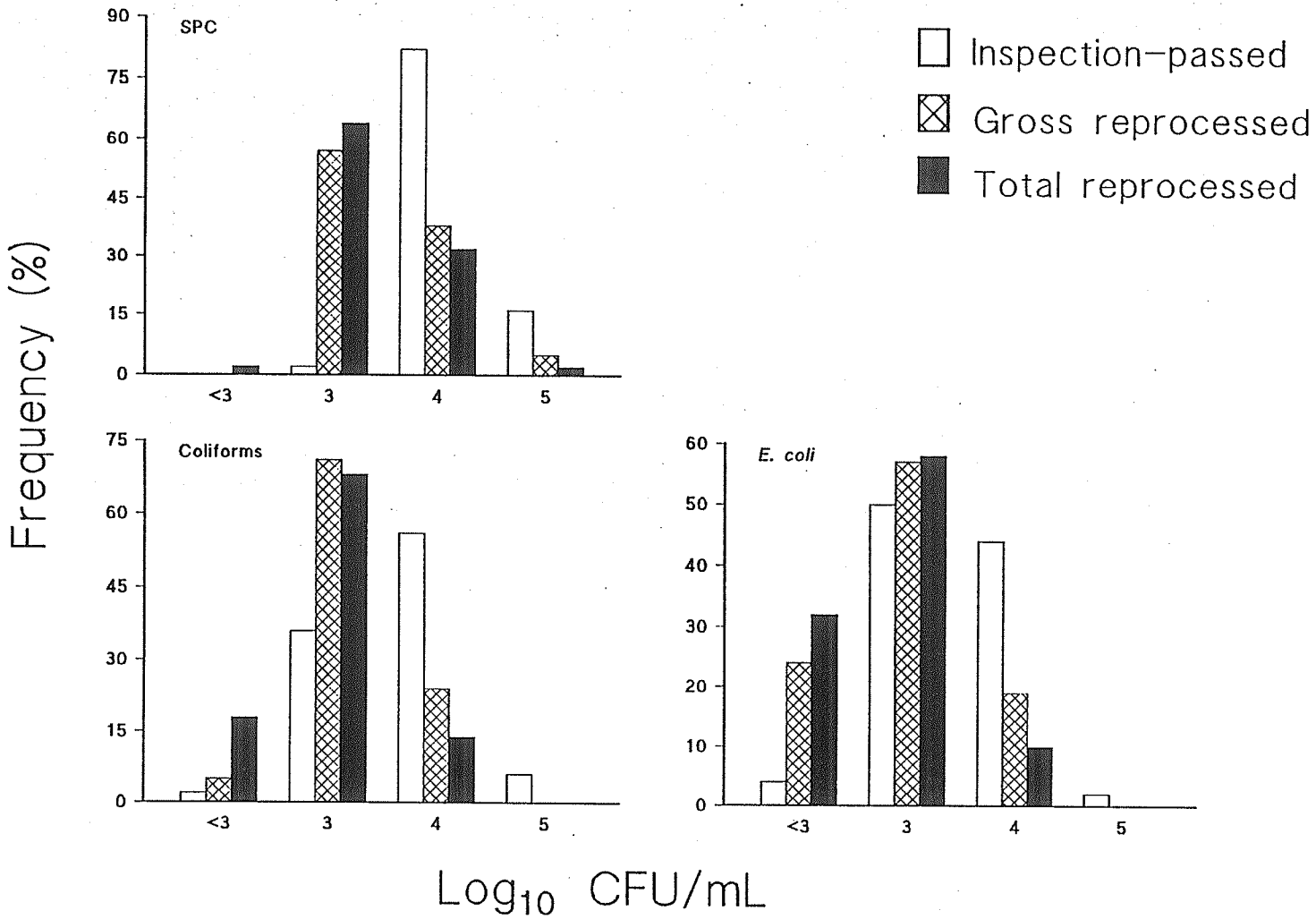
Approximately 15.5% of all carcasses examined (54/349) contained *Salmonella*. The species included (frequency, %): *S. agona*, (3.7); *S. albert* (5.6); *S. hadar* (14.8); *S. heidelberg* (3.7); *S. kingston* (3.7); *S. muenchens* (33.3) and *S. thompson* (35.2). In contrast *Campylobacter* was detected in approximately 80% of all carcasses examined (172/214). Of the *Campylobacters* isolated, 80% were identified as *C. jejuni*.

TABLE 3. Microbial comparison of inspection passed (washed) and reprocessed carcasses sampled by a whole carcass rinse method.

Organism	Inspection passed	Reprocessed		
		Gross	Light	Total
SPC	[a]4.67±0.35	4.10±0.53*	3.78±0.45*	3.92±0.51*
Coliform	4.17±0.51	3.70±0.59*	3.29±0.48*	3.46±0.56*
E. coli	3.98±0.46	3.47±0.57*	3.13±0.40*	3.27±0.50*
Salmonella	[b]32% (16/50)	28% (6/21)	21% (6/29)	24% (12/50)

[a]Means (Log_{10} CFU/ml) ± SD; N=50 for inspection passed and total reprocessed; N=21 for gross and N=29 for light reprocessed; sub-samples of total reprocessed
[b]Percent positives
*Significant at $P<0.05$ for comparison with inspection-passed

Figure 3. Frequency distributions of SPC, coliforms and *E. Coli* (log_{10}CFU/mL) for inspection-passed, total reprocessed and gross reprocessed carcasses.


Inspection-passed
Gross reprocessed
Total reprocessed
Frequency (%)
SPC
Coliforms
E. coli
90
75
60
45
30
15
0
50
40
20
10
<3
3
4
5
Log10 CFU/mL

4.14 Discussion

Recent studies by Blankenship *et al.* (1993) and Waldroup *et al.* (1993) reported results which support the USDA decision to permit reprocessing. Canadian authorities have lacked convincing data on which to base a similar decision. Based on the results of this study, however, it would appear that broiler carcasses with visible internal contamination can be reprocessed to an equal or improved microbiological status compared to conventionally processed (inspection passed) carcasses even without chlorine addition to the water. The off-line spray washer used for reprocessing was shown to be effective even with the worst possible case of contamination except those showing bile staining (no attempt was made to reprocess these carcasses). The microbiological results using either the cup or whole bird rinse methods, obtained for reprocessed carcasses assessed as gross contaminated, support this claim. The volume of water used for reprocessing (6 L/carcass) may be deemed excessive, however, it is believed that this volume could be reduced by further refinement of the spray design and application. Reducing the water levels sprayed externally on the carcasses during reprocessing to comparable levels used in conventional cabinet or inside-outside washers is one possible area of improvement. Additional improvements could involve the use of rotary spray

nozzles and chlorination. Although hyper-chlorination (max. of 20 ppm) is permitted in Canada, its use and safety is increasingly being questioned (Amato, 1993). Lillard (1993) also reported the limited accessibility of chlorine to either attached or entrapped salmonellae on chicken tissue. Trimming the cut edges of the vent opening where necessary would further reduce the water requirement.

The overall incidence of *Salmonella* in this study was about 15.5% which is considerably lower than the level reported by Blankenship *et al.* (1993) and Bailey *et al.* (1991). In these studies, however, all *Salmonella* were detected following a whole bird rinse and in the case of the latter study were obtained from fully processed carcasses. In the case of a whole bird rinse, the expected consequence would be an increase in detection presumably due to the *Salmonella* on the exterior surfaces of the carcasses. Since the primary aim of the study was to evaluate the efficiency of reprocessing, specifically the microbiology of the visceral cavity, it was not deemed necessary to evaluate the entire carcass. Nevertheless when a whole carcass rinse was performed, the level of *Salmonella* among inspection passed and total reprocessed was higher compared to the cup method. This finding although expected is somewhat biased, however, since approx. half of the *Salmonella* obtained following the whole bird rinse were isolated from same day samplings. In addition

all samplings yielded the identical serotype indicating common flock and possible barn hygiene problems.

The fact that the majority of carcasses in this study tested positive for *Campylobacter*, even after washing is an area of concern, perhaps even much more than for *Salmonella*. Although Jones *et al.* (1991) reported that only 52% of carcasses exiting the immersion chiller contained *Campylobacter*, data provided by other researchers (Baker *et al.* 1987; Berndtson *et al.* 1992; Izat *et al.* 1988) corroborate the high incidence rate obtained in this study. The incidence of *Campylobacter* in contaminated, reprocessed and inspection-passed carcasses was not significantly different. Since the *Campylobacter* level would be expected to decrease in carcasses during reprocessing, similar to that observed for *E. coli*, it seems likely that their level is more than casual in nature. Processing contamination would doubtlessly contribute to their high level of detection, however, their anticipated high numbers may also be due to the less than desirable husbandry practices (Jones *et al.* 1991).

4.15 Conclusion

In conclusion, while the reprocessing procedure did not significantly reduce the number of *Salmonella* and *Campylobacter* positive carcasses, the overall microbial status

was at least equivalent to inspection-passed carcasses. Based on these results it would be recommended that reprocessed carcasses be allowed entry to the chilling system following re-inspection.

5. OVERALL CONCLUSIONS

Microbiological aspects of the major steps involved in the production of chilled poultry carcasses were reviewed in this thesis. While it was noted that bacteria are present on broiler carcasses in relatively high numbers, it was apparent that reductions could be made by proper control at each process. In particular, the effective use of water, with or without additives, was shown to be the key element in reducing, or at least maintaining, bacterial counts from one step to the next. This was highlighted in such examples as countercurrent multi-stage scalding, multiple spray washing of carcasses during evisceration, and immersion chilling.

The presence of several species of microbial pathogens in poultry was discussed. While ultimately their fate would be determined by final product handling procedures, the responsibility of processors to control such biological hazards through the implementation of comprehensive HACCP plans was explained. The development of a limited version of such a plan served to demonstrate the steps involved.

Paper 1 showed that at least a 1 log reduction in bacterial counts on broiler carcasses was achieved by the washing effect of immersion chilling. The potential for even

lower counts on chilled carcasses seemed possible by more efficient use of water at the I/O washer and as chiller make-up.

Paper 2 reported the results of studies which demonstrated that carcasses condemned for fecal contamination of the body cavity could be successfully reprocessed to at least the same microbiological status as inspection-passed carcasses. A further significant result was the high detection level for *Campylobacter* on carcasses from both groups. By comparison, *Salmonella* was detected on relatively few carcasses.

It is this author's hope that the experience gained from the investigations reported here will provide the foundation for further research into improved poultry processing. In particular, it would appear that there is potential for more effective use of water to remove more bacteria with the same overall volume. Also, if chiller water can be successfully recycled, some of the water saved could be used for additional pre-chill carcass spray washes.

REFERENCES

Adams, C. 1990. HACCP for poultry inspection. Broiler Industry (1) 42-56.

Agriculture Canada. 1994. HACCP Modelling Workshop, Manual. Food Production and Inspection Branch.

Agriculture Canada. 1982. Manual of procedures. Meat hygiene manual. Chap. 4, Sect. 4.5.3. Ammended 1992. Food Production and Inspection Branch, Agriculture Canada, Ottawa.

Agriculture Canada. 1993. Poultry market report. Agri-food development branch. Agriculture Canada, Ottawa, Canada.

Amato, I. 1993. The crusade against chlorine. Science. 261:152-154.

American Public Health Association. 1992. Compendium of methods for the microbiological examination of foods. 3rd ed., Washington, D.C.

Anon., 1985. Meat and Poultry Inspection: The scientific basis of the nation's program. Food and Nutrition Board Commission on Life Sciences National Research Council. National Academic Press. Washington, D.C. Ch. 8.

Anon.. 1992. HACCP and total quality management - winning concepts for the 90's: a review. Microbiology and food safety committee of the National Food Processors Assoc.. J. Food Prot. 55:459-462.

Anon., 1993. Magpies responsible for Campylobacter outbreak.

Food Safety Note Book. 4 (7/8) 77.

Anon., 1994a. A vision of poultry processing 10 years from now. World Poultry. 10(1/2) 83,84.

Anon., 1994b. Retailers warming up to air chilled chicken. Chicken Forum. Canadian Chicken Marketing Agency. 4(2)4.

Bahk, J. and Marth, E.H. 1990. Listeriosis and *Listeria monocytogenes*. In: Foodborne Diseases (Ed.) Cliver, D.L. Ch. 18.

Bailey, J.S., Thomson, J.E. and Cox, N.A. 1987. Contamination of poultry during processing. In: The Microbiology of Poultry Meat Products. F.E. Cunningham and N.A. Cox (Eds). cademic Press, Inc. New York. Ch.5, p.204.

Bailey, J.S. 1988. Integrated colonization control of *Salmonella* in poultry. Poultry Sci. 67:928-932.

Bailey, J.S., Fletcher, D.L. and Cox, N.A. 1984. Recovery and serotype distribution of *Listeria monocytogenes* from broiler chickens in the southeastern United States. J. Food Prot. 52:148-150.

Bailey, J.S., N.A. Cox, and L.C. Blankenship. 1991. A comparison of an enzyme immunoassay, DNA hybridization, antibody immobilization, and conventional methods for recovery of naturally occurring *Salmonellae* from processed broiler carcasses. J. Food Prot. 54:354-356.

Baker, R.C., Paredes, M.D.C. and Qureshi, R.A. 1987. Prevalence of *Campylobacter jejuni* in eggs and poultry

meat in New York State. Poultry Sci. 66:1766-1770.

Baran, W.L., Dawson, L.E. and Lechowich, R.V. 1973. Influence of chlorine dioxide water treatment on numbers of bacteria associated with processed turkey. Poultry Sci. 52:1053-1058.

Bernard, D. 1994. Industry perspectives on *Listeria monocytogenes* in foods: manufacturing and processing. Dairy, Food and Environ. Sanit. 14:140143.

Berndtson, E., Tivemo, M. and Engvall, A. 1992. Distribution and numbers of *Campylobacter* in newly slaughtered broiler chickens and hens. Int. J. Food Microbiol. 15:45-50.

Blankenship, L.C. 1991. Ed. Colonization control of human bacterial enteropathogens in poultry. Academic Press, Inc. Harcourt Brace Jovanovich, Publishers. San Diego.

Blankenship, L.C., Bailey, J.S., Cox, N.A., Stern, N.J., Brewer, R. and Williams, O. 1993. Two-step mucosal competitive exclusion flora treatment to diminish salmonellae in commercial broiler chickens. Poultry Sci. 72:1667-1672.

Blankenship, L.C., J.S. Bailey, N.A. Cox, M.T. Musgrove, M.E. Berrang, R.L. Wilson, M.J. Rose, and S.K. Dua. 1993. Broiler carcass reprocessing, a further evaluation. J. Food Prot. 56:983-985.

Blankenship, L.C., Cox, N.A., Craven, S.E., Mercuri, A.J., and Wilson, R.L. 1975. Comparison of the microbiological

quality of inspection-passed and fecal contamination-condemned broiler carcasses. J. Food Sci. 40:1237-1238.

Bristol, P. 1992. Safety in numbers. Food in Canada. 52(5)17-20.

Butzler, J.P. and Oosterom, J. 1991. *Campylobacter*: pathogenicity and significance in foods. Int. J. Food Microbiol. 12:1-8.

CCMA, 1993. Data Handbook. Canadian Chicken Marketing Agency. Ottawa, Ontario. p.16.

Campbell, D.F., Johnston, R.W., Campbell, G.S., McClain, D. and Macaluso, J.F. 1983. The microbiology of raw, eviscerated chickens: a ten year comparison. Poultry Sci. 62:437-444.

Chang, Y.H. and Sheldon, B.W. 1989. Application of ozone with physical wastewater treatments to recondition poultry process waters. Poultry Sci. 68:1078-1087.

Clarke, B.J. 1984. An investigation into the feasibility of recycling commercial poultry chiller water following powdered activated carbon treatment. MSc. Thesis. University of Manitoba, Winnipeg, Manitoba, Canada.

Dean, K.H. 1990. HACCP and food safety in Canada. Food Technology. 44(5)172,178.

Dickens, J.A. and Cox, N.A. 1992. The effect of air scrubbing on moisture pickup, aerobic plate counts, *Enterobacteriaceae*, and the incidence of *Salmonellae* on

artifically inoculated broiler carcasses. Poultry Sci. 71:560-564.

Dickson, J.S. and Anderson, M.E. 1992. Microbiological decontamination of food animal carcasses by washing and sanitizing systems: a review. J. Food Prot. 55:133-140.

Dodd, C.E.R., Chaffey, B.J. and Waites, W.M. 1988. Plasmid profiles as indicators of the source of contamination of *Staphylococcus aureus* endemic within poultry processing plants. Appl. and Environ. Microbiol. 54:1541-1549.

Doyle, M.P. and Cliver, D.O. 1990. Salmonella. In: Foodborne Diseases. Ed. Cliver, D.O. Academic Press, Inc. Harcourt, Brace, Jovanovich, Publishers, San Diego. Ch. 11.

Doyle, M.P. 1990. *Campylobacter jejuni*. In: Foodborne Diseases. Ed. Cliver, D.O. Academic Press, Inc. San Diego. Ch. 14.

Doyle, M.P. and Cliver, D.O. 1990. *Escherichia coli*. In: Foodborne diseases. Cliver, D.O. (Ed.) Academic Press, Inc. San Diego. Ch. 13.

Doyle, M.P. and Schoeni, J.L. 1987. Isolation of *Escherichia coli* 0157:H7 from retail fresh meats and poultry. Appl. Environ. Microbiol. 53:2394-2396.

Entis, P. 1989. Hydrophobic grid membrane filter/MUG method for total coliform and *Escherichia coli* enumeration in foods: collaborative study. J. Assoc. Off. Anal. Chem. 72:936-949.

Entis, P. and P. Boleszczuk. 1991. Rapid Detection of *Salmonella* in foods using EF-18 agar in conjunction with the hydrophobic grid membrane filter. J. Food Prot. 54:930-934.

Federal Register, 1978. Poultry slaughtering practices, final rule. 43:no. 60, (Tuesday, March 28, 1978), 12846-12847.

Firstenberg-Eden, R., Notermans, S. and van Schothorst, M. 1978. Attachment of certain bacterial strains to chicken and beef meat. J. Food Safety 1:217-228.

Forsythe , R.H. and Waldroup, A.L. 1992. Safe meat and poultry: an industry achievement. Dairy, Food and Environ. Sanit. 12: 149-153.

Franco, D.A. 1988. *Campylobacter* species: considerations for controlling a foodborne pathogen. J. Food Prot. 51:145-153.

Frazier, W.C. and Westerhoff, D.C. 1988. Food Microbiology. 4th Ed. McGraw-Hill Book Company. New York. p. 414-419, 430.

Gill, C.O. and Newton, K.G. 1978. The ecology of bacterial spoilage of meat at chill temperature. Meat Sci. 2, 207-217.

Goren, E.W., de Jong, A., Dooruenbal, P., Bolder, N.S., Mulder, R.W.A.W. and Jensen, A. 1988. Reduction of *Salmonella* infection of broilers by spray application of intestinal microflora: a longitudinal study. Vet. Q.

10:249-255.

Heidelbaugh, N.D. and Menning, E.L. 1993. Safety of foods of animal origin. J. Am. Vet. Med. Assoc. 203:199-204.

Hewell, J. 1994. Controlling Yield. Broiler Industry. 57(1) 42-48.

Hudson, W.R. and Mead, G.C. 1989. Listeria contamination at a poultry processing plant. Letters in Appl. Microbiol. 9:211-214.

Izat, A.L., Gardner, F.A., Denton, J.H. and Golan, F.A. 1988. Incidence and level of *Campylobacter jejuni* in broiler processing. Poultry Sci. 67:1568-1572.

Izatt, A.L., Colberg, M., Driggers, C.D. and Thomas, R.A. 1989. Effects of sampling methods and feed withdrawal period on recovery of microorganisms from poultry carcasses. J. Food Prot. 52:480-483.

James, W.O., Brewer, R.L., Prucha, J.C., Williams, W.O. and Parham, D.R. 1992a. Effects of chlorination of chill water on the bacteriologic profile of raw chicken carcasses and giblets. J. Am. Vet. Med. Assoc. 200:60-63.

James, W.O., Prucha, J.C., Brewer, R.L., Williams, W.O., Christensen, W.A., Thaler, A.M., and Hogue, A.T. 1992b. Effects of countercurrent scalding and postscald spray on the bacteriologic profile of raw chicken carcasses. J. Am. Vet. Med. Assoc. 201:705-708.

James, W.O., Williams, W.O. Prucha, J.C., Johnson. R. and Christensen, W. 1992c. Profile of selected bacterial counts and *Salmonella* prevalence on raw poultry in a poultry slaughter establishment. J. Am. Vet. and Med. Assoc. 200(1)57-59.

James, W.O., Prucha, J.C. and Brewer, R.L. 1993. Cost-effective techniques to control human enteropathogens on fresh poultry. Poultry Sci. 72:1174-1176.

Johnson Food Equipment Inc. 2955 Fairfax Trafficway, Kansas City, Kansas. USA.

Johnson, J.L., Doyle, M.P. and Cassens, R.G. 1990. *Listeria monocytogenes* and other *Listeria* spp. in meat and meat products: a review. J. Food Prot. 53:81-91.

Jones, F.T., Axtell, R.C., Rives, D.V., Scheideler, S.E., Tarver, F.R., Walker, R.L. and Wineland, M.J. 1991a. A survey of *Salmonella* contamination in modern broiler production. J. Food Prot. 54:502-507.

Jones, F.T., Axtell, R.C., Rives, D.V., Scheiderer, S.E., Tarver, F.R., Walker, R.L. and Wineland, M.J. 1991b. A survey of *Campylobacter jejuni* contamination in modern broiler production and processing systems. J. Food Prot. 54:259-262.

Kelly, J. 1993. USDA prepares for *E. coli* combat. Meat and Poultry. 39 (4) 8.

Kim, J.-W. and Doores, S. 1993a. Influence of three

defeathering systems on microtopography of turkey skin and adhesion of *Salmonella typhimurium*. J. Food Prot. 56:286-291, 305.

Kim, J.-W. and Doores, S. 1993b. Attachment of *Salmonella typhimurium* to skin of turkey that had been defeathered through three different systems: scanning electron microscope examination. J. Food Prot. 56: 395-400.

Kosaric, N., Cairns, W.L. and Gray, N.C.C. 1987. Microbial de-emulsifiers. In: Biosurfactants and biotechnology. Surfactant science series. Vol. 25. Kosaric, N., Cairns, W.L. and Gray, N.C.C. Eds. Marcel Dekker, Inc. New York. pp. 247-321.

Krizner, K. 1993. Bird on a hot seat. Poultry Proc. 8(1) 50-52.

Leutchefeld, N.W. and Wang, W.L. 1981. *Campylobacter fetus* subsp. *jejuni* in a turkey processing plant. J. Clin. Microbiol. 13:266-268.

Lillard, H.S. 1980. Effect on broiler carcasses and water of treating chilling water with chlorine or chlorine dioxide. Poultry Sci. 59:1761

Lillard, H.S. 1988. Comparison of sampling methods and implications for bacterial decontamination of poultry carcasses by rinsing. J. Food Prot. 51:405-408.

Lillard, H.S. 1989a. Incidence and recovery of Salmonellae and other bacteria from commercially processed poultry

carcasses at selected pre- and post-evisceration steps. J. Food Prot. 52:88-91.

Lillard, H.S. 1989b. Factors affecting the persistance of *Salmonella* during the processing of poultry. J. Food Prot. 52:829-832.

Lillard, H.S. 1990. The impact of commercial processing procedures on the bacterial contamination and cross-contamination of broiler carcasses. J. Food Prot. 53:202-204.

Lillard, H.S. 1993. Bactericidal effect of chlorine on attached salmonellae with and without sonification. J. Food Prot. 56:716-717.

Lillard, H.S. and Thomson, J.E. 1983. Efficacy of hydrogen peroxide as a bactericide in poultry chiller water. J. Food Sci. 48:125-126.

Lior, H. 1984. New, extended biotyping scheme for *Campylobacter jejuni*, *Campylobacter coli*, and *Campylobacter laridis*. J. Clin. Microbiol. 20:636-640.

Mackey, B. 1989. The incidence of food poisoning bacteria on red meat and poultry in the United Kingdom. Food Sci. and Technol. Today. 3 (4) 246-250.

Martin, G.T. 1993. Bankable yield is everybody's business. Broiler Industry. 56(12)26-34.

Masri, M.S. 1986. Chlorinating poultry chiller water: The generation of mutagens and water re-use. Food Chem.

Toxic. 24:923-930.

Matilla, T. and Frost, A.J. 1988. The growth of potential food poisoning organisms on chicken and pork muscle surfaces. J. Appl. Bacteriol. 65:455-461.

May, K.N. 1974. Changes in microbial numbers during final washing and chilling of commercially slaughtered broilers. Poultry Sci. 53:1282-1285.

Mayes, T. 1992. Simple user's guide to the hazard analysis critical control point concept for the control of food microbiological safety. Food Control. 3: 14-19.

Mead, G.C., 1989. Hygienic problems and control of process contamination. In: Processing of Poultry. Mead, G.C. (Ed.). Elsevier Applied Science. London. p. 196.

Mead, G.C. and Thomas, N.L. 1973. The bacteriological condition of eviscerated chickens processed under controlled conditions in a spin-chilling system and sampled by two different methods. Br. Poultry Sci. 14:413-419.

Mead, G.C. and Dodd, C.E.R. 1990. Incidence, origin and significance of staphylococci on processed poultry. J. Appl. Bacteriol. Symposium Supplement. 1990, 81S-91S.

Mead, G.C., Hudson, W.R. and Hinton, M.H. 1993. Microbiological survey of five poultry processing plants in the UK. Br. Poultry Sci. 34:497-503.

Mossel, D.A.A. and Struijk, C.B. 1993. Foodborne illness 1993:

updating Wilson's triad. The Lancet. 342:1254

Mulder, R.A.W. 1984. Microorganisms in poultry processing. Poultry International. 23(5) 76-78, 80.

Mulder, R.W.A.W. 1993 Beat and control the microbes. Misset - World Poultry. 9(5)69-73.

Munroe, D.L., Prescott, J.F. and Penner, J.L. 1983. *Campylobacter jejuni* and *Campylobacter coli* serotypes isolated from chickens, cattle and pigs. J. Clin. Microbiol. 18:877-878.

Notermans, S., Dufrenne, J. and Van Leeuwen, W.J. 1982. Contamination of broiler chickens by *Staphylococcus aureus* during processing; incidence and origin. J. Appl. Bacteriol. 52:275-280.

Notermans, S. and Kampelmacher, E.H. 1974. Attachment of some bacterial strains to the skin of broiler chickens. Br. Poult. Sci. 15:573-585.

Notermans, S., Terbijhe, R.J. and Van Schothorst, M. 1980. Removing fecal contamination of broilers by spray-cleaning during evisceration. Br. Poultry Sci. 21:115-121.

Nunas, F. 1988. Quality control starts before catching. World Poultry. 4 (8) 29-30.

Nurmi, E. and Rantala, M. 1973. New aspects of *Salmonella* infection in broiler production. Nature. 241:210-211.

Park, C.E. 1992. Isolation of *Campylobacter* from food.

MFLP-46. Health Protection Branch, Bureau of Microbial Hazards, Food Directorate, Ottawa, Canada.

Park, R.W.A., Griffiths, P.L. and Moreno, G.S. 1991. Sources and survival of campylobacters: relevance to enteritis and the food industry. *In*: Pathogens in the environment. Austin, B. (Ed.) The Society for Appl. Bacteriol. Symposium Series No. 20. Blackwell Scientific Publications, Oxford. 973-1065.

Picek, C.R. 1992. Reconditioning and reuse of chilled water for poultry and food processing. Food Science and Technology Abstracts. 1993. 25(7)7S148, p.228.

Potter, M.E. 1992. The changing face of foodborne disease. J. Am. Vet. Med. Assoc. 201:250-253.

QA Laboratories Ltd. 1989. ISO-GRID® Methods manual. 3rd edition. QA Laboratories Ltd., Toronto, Canada.

Rigby, C.E., Pettit, J.R., Bentley, A.H., Spencer, J.L., Solomons, M.O. and Lior, H. 1982. The relationship of salmonellae from infected broiler flocks, transport crates or processing plants to contamination of eviscerated carcasses. Can. J. Comp. Med. 46:272-278.

Roberts, T.A. 1992. Microbiological control of food production. In: Microbial Food Poisoning. Eley, A.R. (Ed.) Chapman and Hall. London. p. 159.

Rorvik, L.M. and Yudestad, M. 1991. *Listeria monocytogenes* in foods in Norway. Int. J. Food and Environ. Sanit.

12:149-153.

Sanderson, K. Thomas, C.J. and McMeekin, T.A. 1989. Mechanism of adhesion of *Salmonella* to chicken muscle connective tissue. J. Appl. Bacteriol. 67(6) XXIV (Abstr.).

Shane, S. 1993. A head to tail feather investigation. Poultry Processing. 8(1)114.

Sheldon B.W. and Brown A.L. 1986. Efficacy of ozone as a disinfectant for poultry carcasses and chill water. J. Food Sci. 51:305-309.

Simonsen, B. 1989. Microbial criteria for poultry products. In: Processing of Poultry. G.C. Mead (Ed). Elsevier Applied Science. London. Ch. 7, p.231.

Stern, N.J. and Line, J.E. 1992. Comparison of three methods for recovery of *Campylobacter* spp. from broiler carcasses. J. Food Prot. 55:663-666.

Surkiewicz, B.F., Johnston, R.W., Moran, A.B. and Krumm, G.W. 1969. A bacteriological survey of chicken eviscerating plants. Food Technol. 23:80-85.

Thayer, S.G. and Walsh, J.L. 1993. Evaluation of cross-contamination on automatic viscera removal equipment. Poultry Sci. 72:741-746.

Thiessen, G.P., Usborne, W.R., and Orr, H.L. 1984. The efficacy of chlorine dioxide in controlling *Salmonella* contamination and its effect on product quality of chicken broiler carcasses. Poultry Sci. 63:647.

Thiessen, G.P. 1985. The efficacy of reprocessing, chlorine dioxide and inside-outside carcass washers in improving poultry processing practices. Agriculture Canada, Department of Supply and Service, File No. SISZ 01199-4-E010, Contract Serial No. OSZ84-00065.

Thomas, C.J. and McMeekin, T.A. 1981. Attachment of *Salmonella* spp. to chicken muscle surfaces. Appl. Environ. Microbiol. 42:130-134.

Thomson, J.E., Whitehead, W.K. and Mercuri, A.J. 1974. Chilling poultry meat - a literature review. Poultry Sci. 53:1268-1281.

Todd, E.C.D. 1987. Impact of spoilage and foodborne diseases on national and international economies. Int. J. Food Microbiol. 4:83-100.

Tompkin, R.B. 1990. The use of HACCP in the production of meat and poultry products. J. Food Prot. 53:795-803.

Tsai, L-S., Schade, J.E. and Molyeax, B.T. 1992. Chlorination of poultry chiller water: Chlorine demand and disinfection efficiency. Poultry Sci. 71:188-196.

United States Department of Agriculture. 1990. Poultry Products Inspection Regulations. 9CFR, Chap. 3, Sect. 381.76C January 1. U.S. Department of Agriculture, Washington, D.C.

Vacinek, A.A. 1972. Transient cooling, organoleptic quality and moisture exchange in crust frozen air blast chilled

poultry carcasses. M.S. Thesis, University of Georgia, Athens, Ga. USA. Cited by: Thomson, J.E., Whitehead, W.K. and Mercuri, A.J. 1974. Chilling poultry meat - a literature review. Poultry Sci. 53:1268-1281.

Varnam, A.H. and Evans, M.G. 1991. Foodborne Pathogens: An Illustrated Text. Wolfe Publishing Ltd. London. pp. 430-432.

Veerkamp, C.H. 1985. Developments in poultry chilling. Poultry Int. 24(2)68-74.

Veerkamp, C.H. 1992. Multi-stage scalding. Broiler Industry. 55(11)24-28.

Voelker, R. 1994. Foodborne illness problems more than enteric. J. Am. Med. Assoc. 271:(1)8-9, 11.

Vogt, R.L., Sours, H.E., Barrett, T., Feldman, R.A., Dickinson, R.J. and Witherell, L. 1982. *Campylobacter enteritis* associated with contaminated water. Annals of Internal Med. 96:292-296.

Vorster, S.M., Greebe, R.P. and Nortje, G.L. 1994. Incidence of *Staphylococcus aureus* and *Escherichia coli* in ground beef, broilers and processed meats in Pretoria, South Africa. J. Food Prot. 57:305-310.

Vranic, V., Selakovic, I., Radenovic, D., and Vojinovic, G. 1992. Microbiological aspects of chilling of poultry meat. Tehnologija Mesa. 33(1) 18-22.

Vranic, V., Nedeljkovic, L.J. and Veljic, Z. 1991. Current

methods for chilling of poultry and their further improvement. Tehnologija Mesa. 32(3) 109-114.

Wabeck, D.J. 1972. Feed and water withdrawal time relationship to processing yield and potential fecal contamination of broilers. Poultry Sci. 51:1119-1121.

Waldroup, A.L., Rathgeber, B.M., Forsythe, R.H. and Smoot, L. 1992. Effects of six modifications on the incidence and levels of spoilage and pathogenic organisms on commercially processed postchill broilers. J. Appl. Poultry Res. 1:226-234.

Waldroup, A.L., B.M. Rathgeber, R.E. Hierholzer, L. Smoot, L.M. Martin, S.F. Bilgili, D.L. Flethcher, T.C. Chen, and C.J. Wabeck. 1993. Effects of reprocessing on microbiological quality of commercial prechill broiler carcasses. J. Appl. Poultry Res. 2:111-116.

Wassenaar, T.M., van der Zeijst, .A.M., Ayling, R., and Newell, D.G. 1993. Colonization of chicks by motility mutants of *Campylobacter jejuni* demonstrates the importance of flagellin A expression. J. Gen. Microbiol. 139:1171-1175.

Wesley, R.L. 1977. The effect of metered chiller input volume on poultry carcass quality. Poultry Sci. 59:1769.

Wierup, M., Wold-Troell, M., Nurmi, E. and Hakkinen, M.M. 1988. Epidemiological evaluation of the *Salmonella* controlling effects of a nationwide use of competitive

exclusion culture in poultry. Poultry Sci. 67:1026-1033.

Yildiz, A. and Diker, K.S. 1992. *Campylobacter* contamination in chicken carcasses. Doga Turkish J. of Vet. and An. Sci. 16:433-439.