EVOLUTIONARY ALGORITHMS WITH AVERAGE CROSSOVER AND POWER HEURISTICS FOR AQUACULTURE DIET FORMULATION

ROSSHAIRY ABD RAHMAN

DOCTOR OF PHILOSOPHY
UNIVERSITI UTARA MALAYSIA
2014

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to:

Dean of Awang Had Salleh Graduate School of Arts and Sciences
UUM College of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok
Kedah Malaysia

Abstrak

Industri penternakan akuakultur merupakan salah satu industri yang paling penting di Malaysia kerana ia menjana pendapatan kepada pertumbuhan ekonomi dan menghasilkan sumber makanan utama kepada negara. Salah satu tunggak dalam industry penternakan akuakultur merupakan formulasi diet makanan untuk haiwan, yang juga dikenali sebagai kombinasi atau formulasi bahan makanan.Walau bagaimanapun, kos operasi komponen pemakanan dalam industry akuakultura dalah yang paling mahal kosnya, dan ini menyebabkan banyak kajian dijalankan berkaitan formulasi diet. Kekurangan kajian yang melibatkan pembinaan model telah memberikan motivasi untuk mengkaji formulasi diet, iaitu mencari kombinasi terbaik daripada bahan makanan yang dapat memenuhi keperluan pemakanan dengan kos yang minimum. Oleh itu, tesis ini mengkaji penggunaan Algoritma Evolusi (EA) bagi mencadangkan penyelesaian formulasi diet untuk penternakan akuakultur, khususnya udang. Dalam usaha untuk mendapatkan kombinasi bahan yang terbaik, kaedah penapisan heuristik yang dikenali sebagai Heuristik Kuasa diperkenalkan di peringkat pemulaan dalam metodologi EA. Ia berupaya menapis beberapa bahan yang tidak diingini daripada senarai bahan pilihan yang telah dikenalpasti daripada pangkalan data, yang mana ia boleh membawa kepada satu penyelesaian yang tidak diingini. Kejayaan model EA yang dicadangkan ini juga bergantung kepada operator baharu bagi pemilihan dan penyilangan, yang dapat meningkatkan prestasi penyelesaian secara keseluruhan. Tiga model utama EA telah dibangunkandengan mekanisma pemulaan yang baharu, serta operator pemilihan dan operator penyilangan yang pelbagai. Keputusan kajian mendapati model EA-PH-RWS-Avg adalah yang paling berkesan dalam memberikan hasil penyelesaian terbaik dengan nilai penalti paling minimum. Model baharu yang dicadangkan ini adalah efisien dan mampu disesuaikan dengan perubahan dalam parameter, justeru dapat membantu pengguna menyelesaikan masalah berkaitan formulasi diet udang, khususnya menggunakan bahan tempatan. Selain itu, strategi formulasi diet ini juga menyediakan elemen berasaskan pilihan pengguna untuk menentu bahan pilihan makanan dan jumlah berat bahan yang sesuai.

Kata Kunci: Algoritma evolusi, Heuristik kuasa, Operator penyilangan purata, Formulasi diet, Kombinasi pemakanan

Abstract

The aquaculture farming industry is one of the most important industries in Malaysia since it generates income to economic growth and produces main source of food for the nation. One of the pillars in aquaculture farming industries is formulation of food for the animal, which is also known as feed mix or diet formulation. However, the feed component in the aquaculture industry incurs the most expensive operational cost, and has drawn many studies regarding diet formulation. The lack of studies involving modelling approaches had motivated to embark on diet formulation, which searches for the best combination of feed ingredients while satisfying nutritional requirements at a minimum cost. Hence, this thesis investigates a potential approach of Evolutionary Algorithm (EA) to propose a diet formulation solution for aquaculture farming, specifically the shrimp. In order to obtain a good combination of ingredients in the feed, a filtering heuristics known as Power Heuristics was introduced in the initialization stage of the EA methodology. This methodology was capableof filtering certain unwanted ingredients which could lead to potential poor solutions. The success of the proposed EA also relies on a new selection and crossover operators that have improved the overall performance of the solutions. Hence, three main EA model variants were constructed with new initialization mechanism, diverse selection and crossover operators, whereby the proposed EA-PH-RWS-Avg Model emerged as the most effective in producing a good solution with the minimum penalty value. The newly proposed model is efficient and able to adapt to changes in the parameters, thus assists relevant users in managing the shrimp diet formulation issues, especially using local ingredients. Moreover, this diet formulation strategy provides user preference elements to choose from a range of preferred ingredients and the preferred total ingredient weights.

Keywords: Evolutionary algorithm, Power heuristics, Average crossover operator, Diet formulation, Feed mix

Acknowledgement

In the name of Allah, the Beneficent, the Merciful.

This work simply could not have been possible without the assistance and encouragement from many others. First and foremost, I would like to thank the most important people that make this thesis possible. The person is my supervisor, Associate Professor Dr. Razamin Ramli. I sincerely thank her for her support and guidance throughout the journey of my studies. I would also like to thank my former supervisor the late Associate Professor Dr. Ang Chooi Leng for her motivation and inspiration during her supervision at the difficult early stage of my journey.

I would like to acknowledge the support from all the persons involved in the process of data gathering including research officers, manufacturers and farmers. I would also like to express my gratitude to Universiti Utara Malaysia for the sponsorship given. Thanks also to the Dean and management staff of the School of Quantitative Sciences.

I am also grateful to all my friends for being there with me throughout the ups and downs in my PhD journey. They include Adyda, Nerda, Shery, Linda, Kak Coknin, Kak Aza, Kak Zura, Kak Deqta, Kak Kiah, Ja, Haslinda, Huai Tein and many more whose names I simply cannot mention here simply because they are so many of them.

Finally, I am forever indebted to my family who has always been understanding and supportive throughout my study. My special thanks go to my beloved husband,Ku Hushaini Ku Aris, for his patience, care, love and prayer, and to my children, Nina, Alya, and Irham. Not to forget my special thanks to my mother, sisters, brothers, nephews and nieces for their constant support and prayer.Thank you all from the bottom of my heart. May Allah bless you all...

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

ABC	Artificial Bee Colony
AI	Artificial Intelligence
BCGA	Binary Coded Genetic Algorithm
BSI	Bee Swarm Intelligence
CCP	Chance Constrained Programming
DOF	Department of Fisheries
DP	Dynamic Programming
DSS	Decision Support System
EA	Evolutionary Algorithm
EAA	Essential Amino Acids
FAO	Food and Agriculture Organization
FLP	Fuzzy Linear Programming
GA	Genetic Algorithm
GP	Goal Programming
GUI	Graphical User Interface
IFAH	International Federation for Animal Health
LP	Linear Programming
MCDM	Multi Criteria Decision Making
MCS	Monte Carlo Simulation
MOFP	Multi Objective Fractional Programming
MOP	Multi Objective Programming
MGP	Multi Goal Programming
NLP	Nonlinear Programming
NRC	National Research Council
OR	Operations Research
PSM	Pearson's square method
QP	Quadratic Programming
RCGA	Real Coded Genetic Algorithm
RPV	Roulette penalty value
RF	Risk Formulation
RT	Roulette-Tournament

RWS	Roulette Wheel Selection
SAE	Simultaneous Algebraic Equations
Sec	Second
TE	Trial and Error method
QB	Queen-Bee

CHAPTER 1

INTRODUCTION

Animal source food is important for humans to avoid malnutrition since it provides a lot of nutrients needed by a human body often limited in a diet (Demment, Youngy, & Sensenig, 2003; Neumann, Harris, & Rogers, 2002). These nutrients include protein, iron, vitamin, carbohydrate, potassium and sodium, which contribute in generating new tissues and producing energy, and have diversified benefits to humans. However, only healthy aquaculture can provide healthy food in adequate quantity for human consumption (Hansard Team Kenya National Assembly, 1993; International Federation for Animal Health [IFAH], 2011). Among the animals that contribute a good source of food are fish, mussels and shrimps.

1.1 Challenges in aquaculture industry

Growth in the world population has increased demand for healthy animal source food including aquaculture produce. As captured aquacultures can no longer meet the high market demand, the farming industry is forced to increase the production of farmed animals to fulfil the current needs. Like other industries, the main objective of a food producing industry is to generate maximum income and profit. Therefore, farmers have to strategize in order to minimize their production costs and sell their produce at the highest possible price. In addition to market demand and size, farmed animal price depends on its appearance such as stress and unhealthy eyes (Blue et al., 2007). Sufficient nutritional need is important to obtain good appearance and healthy body, thus contributing to a higher sale market value. Farmers need to provide enough nutritious food to ensure that their farmed animals receive adequate nutrition.

The contents of the thesis is for internal user only

REFERENCES

Abu Hassan, I., Hanafi, H.H., Che Musa, C.U., Pathmasothy, S. (1988, 25-29 October). Status of shrimp and finfish feeds in Malaysia. *Report of the Workshop on Shrimp and Finfish Feed Development*, Retrieved on April 5, 2010, from Food and Agriculture Organization (FAO) Corporate Document Repository.

Anderson, A. M., & Earle, M. D. (1983). Diet planning in the third world by linear and goal programming. *The Journal of the Operational Research Society, 34*, 9-16.

Afolayan, M. O., & Afolayan, M. (2008). Nigeria oriented poultry feed formulation software requirements. *Journal of Applied Sciences Research, 4*(11), 1596-1602.

Akiyama, D. M. (1992). *Future considerations for shrimp nutrition and the aquaculture feed industry.* Paper presented at the special session on shrimp farming, Louisiana, USA.

Al-Deseit, B. (2009). Least cost broiler ration formulation using linear programming technique. *Journal of Animal and Veterinary Advances, 8*(7), 1274-1278.

Alexander, D. L. J., Morel, P. C. H., & Wood, G. R. (2006). Feeding strategies for maximising gross margin in pig production. In J. D. Pintér, (Eds.), *Global optimization: scientific and engineering case studies* (pp. 33-43). New York: Springer.

Alkhazaleh, H. A. K. (2010). *Menu planning prototype system for Malaysian athletes*. Unpublished master's thesis, Universiti Utara Malaysia.

All about circuit. (2012). Retrieved on December 1, 2013 from http://www.allaboutcircuits.com/vol_5/chpt_4/11.html

Anderson, A. M., & Earle, M. D. (1983). Diet planning in the third world by linear and goal programming. *The Journal of the Operational Research Society*, *34*, 9-16.

Aytug, H., & Koehler, G. J. (2000). New stopping criterion for genetic algorithms. *European Journal of Operational Research, 126* (3), 662-674.

Azeem, M. F., & Saad, A. M. (2004). Modified queen bee evolution based genetic algorithm for tuning of scaling factors of fuzzy knowledge base controller. Proceeding of The India Annual Conference (IEEE Indicon 2004) (pp. 299-303). Kharagpur, India.

Babić, Z., & Perić, T. (2011). Optimization of livestock feed blend by use of goal programming. *International Journal of Production Economics, 130*, 218-223.

Babu, G. P. & Murty, M. N. (1993). A near-optimal initial seed value selection in *k*-means means algorithm using a genetic algorithm. *Pattern Recognition Letters, 14*(10), 763-769.

Babu, S., & Sanyal, P. (2009). *Food security, poverty and nutrition policy analysis: Statistical methods and applications*. Washington, DC, USA: Academic Press.

Bäck, T. (2000). Binary strings. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary computation 1: Basic algorithms and operators* (pp. 132-135). Bristol: Institute of Physics Publishing.

Bailleul, P. J. D., Rivest, J., Dubeau, F., & Pomar, C. (2001). Reducing nitrogen excretion in pigs by modifying the traditional least-cost formulation algorithm. *Livestock Production Science, 72*, 199-211.

Balintfy, J. L., Ross, Z. T., Sinha, P.,& Zoltners, A. A. (1978). A mathematical programming system for preference and compatibility maximized menu planning and scheduling. *Mathematical Programming, 15*, 63-76.

Barbieri, M. A., & Cuzon, G. (1980). Improved nutrient specification for linear programming of penaeid rations. *Aquaculture, 19*, 313-323.

Bauer, R. J. (1994). *Genetic algorithms and investment strategies*. New York: John Wiley & Sons.

Bauer, W., Prentice-Hernandez, C., Tesser, M. B., Wasielesky Jr., W., Poersch, L. H. S.. (2012). Substitution of fishmeal with microbial floc meal and soy protein concentrate in diets for the pacific white shrimp *Litopenaeus vannamei*. *Aquaculture, 342–343, 112-116.*

Beasley, D. (2000). Possible applications of evolutionary computation. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary computation 1: Basic algorithms and operators* (pp. 4-19). Bristol: Institute of Physics Publishing.

Becker, G. S. (2008). *Livestock feed costs: Concerns and options.* The Library of Congress. Retrieved on March 27, 2012, from http://www.nationalaglawcenter.org/assets/crs/RS22908.pdf

Bhanja, U., Mahapatra, S., & Roy, R. (2013). QoT aware evolutionary programming algorithm for transparent optical networks.*International Journal for Light and Electron Optics*, *124*(23), 6391-6399.

Blickle, T. (2000). Tournament selection. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary computation 1: Basic algorithms and operators* (pp. 181-186). Bristol: Institute of Physics Publishing.

Blue, N., Brindle, B., Chase, D., Jaipaul, R., Machielse, M., Melvill, L., et al. (October 25, 2007). Economics and marketing: Marketing alternatives for feeder cattle. *Alberta Feedlot Management Guide: Alberta Agriculture Market Specialists.* Retrieved on April 18, 2011, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/beef11849

Booker, L. B., Fogel, D. B. Whitley, D, Angeline, P. J.,& Eiben, A. E. (2000). Binary strings. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary computation 1: Basic algorithms and operators* (pp. 256-307). Bristol: Institute of Physics Publishing.

Burke, E. K., & Kendall, G. (2005). Introduction. In E. K. Burke, & G. Kendall (Eds.), *Search methodologies: Introductory tutorials in optimization and decision support techniques* (pp. 5-18). New York: Springer.

Cadenas, J. M., Pelta, D. A., Pelta, H. R., & Verdegay, J. L. (2004). Application of fuzzy optimization to diet problems in Argentinean farms. *European Journal of Operational Research*, *158*, 218-228.

Castrodeza, C., Lara, P., & Peña, T. (2005). Multicriteria fractional model for feed formulation: Economic, nutritional and environmental criteria. *Agricultural Systems*, *86*, 76-96.

Chakeredza, S., Akinnifesi, F. K., Ajayi, O. C., Sileshi, G., Mngomba, S., & Gondwe, F. M. T. (2008). A simple method of formulating least-cost diets for smallholder dairy production in sub-Saharan Africa. *African Journal of Biotechnology, 7*(16), 2925-2933.

Chang, P-C., Chen, M-H, Tiwari, M. K. & Iquebal, A. S. (2013). A block-based evolutionary algorithm for flow-shop scheduling problem. *Applied Soft Computing*, *13*(12), 4536-4547.

Chappell, A. E. (1974). Linear programming cuts costs in production of animal feeds. *Operational Research Quarterly (1970-1977), 25*(1), 19-26.

Chen, J. T. (1973). Quadratic programming for least-cost feed formulations under probabilistic protein constraints. *American Journal of Agricultural Economics, 55*(2), 175-183.

Chinneck, J. W. (2006). Chapter 14: heuristics for discrete search: Genetic algorithms and simulated annealing. In J. W. Chinneck (Ed.), *Practical optimization: A gentle introduction*. Ontario: Carleton University. Retrieved on January 12, 2013 from http://www.sce.carleton.ca/faculty/chinneck/po/Chapter14.pdf

Chipperfield, A. (1997). Introduction to genetic algorithms. In A. M. S. Zalzala, & P. J. Fleming (Eds.), *Genetic Algorithms in engineering systems*. (pp. 1-41). London: The Institution of Electrical Engineers.

Coello, C. A. (2002). Theoretical and numerical constraint-handling techniques used with evolutionary algorithms: A survey of the state of the art. *Computer Methods in Applied Mechanics and Engineering, 191*, 1245-1287.

Cruz-Suárez, L. E., Nieto-L López, M., Guajardo-Barbosa, C., Tapia-Salazar, M., Scholz, U., & Ricque-Marie, D. (2007). Replacement of fish meal with poultry by-product meal in practical diets for Litopenaeus vannamei, and digestibility of the tested ingredients and diets. *Aquaculture, 272*, 466-476.

Dantzig, G. B. (1990). The diet problem. *Interfaces*, *20* (4), 43-47.

Das, S., Abraham, A., & Konar, A. (2009). *Metaheuristic clustering.* Chennai, India:Springer.

Davis, L. D. (1991). *Handbook of genetic algorithms.*New York: Van Nostrand Reinhold.

Deb, K. (2000a). Introduction to representations. In T. Bäck, D. B. Fogel, & T. Michalewicz (Eds.),*Evolutionary Computation 1: Basic Algorithms and Operators* (pp. 127-131). Bristol: Institute of Physics Publishing.

Deb, K. (2000b). Introduction to selection. In T. Bäck, D. B. Fogel, & T. Michalewicz (Eds.), *Evolutionary Computation 1: Basic algorithms and operators* (pp. 166-171). Bristol: Institute of Physics Publishing.

De Jong, K. A., & Sarma, J. (1993). Generation gaps revisited. In L. D. Whitney (Ed.), *Foundations of genetic algorithms 2*. San Mateo: Morgan Kaufmann.

Deep, K.,& Mebrahtu, H. (2011). Combined mutation operators of genetic algorithm for the traveling salesman problem. *International Journal of Combinatorial Optimization Problems and Informatics*, *2*(3), 1-23.

Deep, K.,& Thakur, M. (2007). A new mutation operator for real coded genetic algorithms. *Applied Mathematics and Computation, 193*(1), 211-230.

Deep, K., Singh, K., Kansal, M. L., & Mohan, C. (2009). A real coded genetic algorithm for solving integer and mixed integer optimization problems. *Applied Mathematics and Computation, 212*, 505-518.

Demment, M. W., Youngy, M. M., & Sensenig, R. L. (2003). Providing micronutrients through food-based solutions: A key to human and national development. *The Journal of Nutrition*, *133*, 3879-3885.

Deng, J., Mai, K., Ai, Q., Zhang, W., Wang, X., Xu, W., & Liufu, Z. (2006). Effects of replacing fish meal with soy protein concentrate on feed intake and growth of juvenile Japanese flounder, *Paralichthys olivaceus. Aquaculture*, *258*, 503–513.

Dobos, R.C., Ashwood, A.M., Moore, K., & Youman, M. (2004). A decision tool to help in feed planning on dairy farms. *Environmental Modelling and Software,19*, 967-974.

Duan, H-B, Xu, C. F. & Xing, Z. H. (2010). A hybrid artificial bee colony optimization and quantum evolutionary algorithm for continuous optimization problems. *International Journal of Neural Systems, 20* (*1*), 39-50.

Eckstein, E. (1970). Is the "diet problem" identical to the "menu planning problem"? *Management Science, 16*(9), 527-528.

Emmert, J. L., & Baker, D. H. (1997). Use of the ideal protein concept for precision formulation of amino acid levels in broiler diets. *Journal of Applied Poultry Research, 6*, 462-470.

Engelbrecht, E. (2008). *Optimising animal diets at the Johannesburg zoo.* Unpublished bachelor's thesis, University of Pretoria, Pretoria, South Africa.

Erban, E. R. Jr., & Pruder, G. D. (1991). A method of economic comparisons for aquaculture diet development. *Aquaculture, 99*, 127-142.

Eshelman, L. J. (2000). Genetic algorithms. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary Computation 1: Basic algorithms and operators* (pp. 64-74). Bristol: Institute of Physics Publishing.

Li, F-C.,& Jin, C-X. (2008). Study on fuzzy optimization methods based on principal operation and inequity degree. *Computers and Mathematics with Applications, 56*, 1545-1555.

Food and Agriculture Organization of the United Nations (FAO). (2013). *Fisheries and Aquaculture Department, 2013* [FishStat Plus]. Available from FAO Web site, http://www.fao.org/fishery/statistics/software/fishstat/en

Food and Agriculture Organization (FAO). (2010). *The state of world fisheries and aquaculture.* Rome: Food and Agriculture Organization of The United Nations.

Fogel, D. B. (1997). The advantages of evolutionary computation. Proceeding of Bio-computing and Emergent Computation (pp 1-11). Skövde, Sweden.

Fogel, D. B. (2000a). Introduction to evolutionary computation. In T. Bäck, D. B. Fogel, & Z. Michalewicz (EDs.), *Evolutionary Computation 1: Basic algorithms and operators* (pp. 1-3). Bristol and Philadelphia: Institute of Physics Publishing.

Fogel, D. B. (2000b). Principles of evolutionary processes. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary Computation 1: Basic algorithms and operators* (pp. 23-26). Bristol and Philadelphia: Institute of Physics Publishing.

Forsyth, D. M. (1995). Chapter 5: Computer programming of beef cattle diet. In T. W. Perry, & M. J. Cecava (Eds.), *Beef cattle feeding and nutrition* (2nd ed., pp. 68). California: Academic Press, Inc.

Fox, J. M., Davis, D. A., & Lawrence, A. L. (2007). Methionine-, sulfur-containing amino acids: Limiting nutrients in commercial formulations? *Global Aquaculture Advocate, 10* (2), 74-77.

Fox, J. M., Davis, D. A., Wilson, M., & Lawrence, A. L. (2006). Current status of amino acid requirement research with marine penaeid shrimp. *Avances en Nutrición Acuícola VIII. VIII Simposium Internacional de Nutrición Acuícola* (pp. 182-196). Nuevo León, México.

Fox, J. M., Lawrence, A. L., & Li-Chan, E. (1995). Dietary requirement for lysine by juvenile penaeus vannamei using intact and free amino acid sources. *Aquaculture, 131*, 279-290.

Fox, J.M., Treece, G.D., & Sanchez, D.R. (2001). *Shrimp nutrition and feed management.* In M. C. Haws, & C. E. Boyd (Eds.), Methods for improving shrimp farming in Central America (pp 65-90). Managua, Nicaragua:University of Central America Press.

Furuya, T., Satake, K., & Minami, Y. (1997). Evolutionary programming for mix design. *Computers and Electronics in Agriculture, 18*, 129-135.

Gillespie, J. R., & Flanders, F. B. (2009). *Modern livestock and poultry production* (8th ed.). Clifton Park, New York, USA: Cengage Learning.

Glen, J. J. (1980). A mathematical programming approach to beef feedlot optimization. *Management Science, 26*(5), 524-535.

Glen, J. J. (1986). A linear programming model for an intensive beef production enterprise. *The Journal of the Operational Research Society, 37*(5), 487-494.

Goldberg, D. E. (1989). *Genetic algorithms in search, optimization, and machine learning*. United States of America: Addison-Wesley Publishing Company, Inc.

Golub, M. (1996). an implementation of binary and floating point chromosome representation in genetic algorithm. Proceedings of 18th International Conference ITI (pp. 417-422). Pula, Croatia.

Grefenstette, J. (2000). Rank-based selection. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary computation 1: Basic algorithms and operators* (pp. 187-194). Bristol: Institute of Physics Publishing.

Guoshuai, L., Kan, Y., Ran, Z & Jiao, Z. (2012). Application of genetic algorithm and annealing genetic algorithm in short-term optimal operation and economical operation of three gorges cascade. *Procedia Engineering, 28,* 81-84.

Guevara, V. R. (2004). Use the nonlinear programming to optimize performance response to energy density in broiler feed formulation. *Poultry Science, 83,* 147-151.

Hansard Team Kenya National Assembly. (1993, April 1, 1993). Kenya National Assembly: Parliamentary Debates, *National Assembly Debates: Official Report: Hansard, 1,* 626.

Hasan, B. H. F.,& Saleh, M. S. M. (2011). Evaluating the effectiveness of the mutation operators on the behaviour of genetic algorithms applied to non-deterministic polynomial problems. *Informatica, 35,* 513-518.

Hecker, F. T., Hussein, W. B., Paquet-Durand, O., Hussein, M. A.,& Becker, T. (2013). A case study on using evolutionary algorithms to optimize bakery production planning. *Expert Systems with Applications*, *40* (17), 6837-6847.

Herrera, F., Lozano, M., & Sánchez, A. M. (2005). Hybrid crossover operators for real-coded genetic algorithms: an experimental study. *Soft Computing, 9*, 280-298.

Herrera, F.,& Lozano, M. (2000). Gradual distributed real-coded genetic algorithms. *IEEE Transactions on Evolutionary Computation, 4,*43–63.

Hertrampf, J. W., Biswal, P. K.,& Mishra, S. K. (2005, June). *AllAboutFeed*. Retrieved on December 1, 2013, from http://www.allaboutfeed.net/Process-Management/Management/2005/6/A-revolutionary-concept-for-shrimp-feeding-AAF010209W/

Herva´ s-Martı´nez, C., & Ortiz-Boyer, D. (2005). Analyzing the statistical features of CIXL2 crossover offspring. *Soft Computing, 9,* 270-279.

Htun, M. S., Thein, T. T., & Tin, P. (2005). *Linear programming approach to diet problem for black tiger shrimp in shrimp aquaculture.* Paper presented at the Information and Telecommunication Technologies, Yangon, Myanmar.

Hung, Y., Chen, C., Shih, C., & Hung, M. (2003). Using tabu search with ranking candidate list to solve production planning problems with setups. *Computers & Industrial Engineering, 45,* 615–634.

The International Federation for Animal Health (IFAH). (2013). Retrieved June 16, 2011 from http://www.ifahsec.org/animal-health/our-story/

Jiao, J., Zhang, Y., & Wang, Y. (2007). A heuristic genetic algorithm for product portfolio planning. *Computers & Operations Research*, *34,* 1777-1799.

Jung, S. H. (2003). Queen-bee evolution for genetic algorithms. *Electronic Letters, 39*(6), 575-576.

Ju, Z. Y., Deng, D-F, Dominy, W. (2012). A defatted microalgae (*Haematococcus pluvialis*) meal as a protein ingredient to partially replace fishmeal in diets of Pacific white shrimp (*Litopenaeus vannamei*, Boone, 1931. *Aquaculture, 354–355*, 50–55.

Karaboga, D. (2005). *An idea based on honey bee swarm for numerical optimization.* Kayseri/Türkiye: Erciyes University, Engineering Faculty.

Karaboga, D., & Basturk, B. (2007). A powerful and efficient algorithm for numerical function optimization: Artificial bee colony (ABC) algorithm. *Journal of Global Optimization, 39*, 459-471.

Karaboga, D., & Basturk, B. (2008). On the performance of artificial bee colony (ABC) algorithm. *Applied Soft Computing, 8*, 687-697.

Karci, A. (2004). Imitation of bee reproduction as a crossover operator in genetic algorithms. In C. Zhang, H. W. Guesgen, & W. K. Yeap (Eds.), *PRICAI 2004, LNAI 3157* (pp. 1015-1016). Springer-Verlag Berlin Heidelberg.

Kinnear Jr, K. E. (2000). Derivative methods in genetic programming. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary Computation 1: Basic algorithms and operators* (pp. 103-113). Bristol and Philadelphia: Institute of Physics Publishing.

Kock, H. C. D., & Sinclair, M. (1987). Multi-mix feedstock problems on microcomputers multi-mix feedstock problems on microcomputers. *The Journal of the Operational Research Society, 38*(7), 585-590.

Kornbluth, J. S. H., & Steuer, R. E. (1981). Multiple objective linear fractional programming. *Management Science, 27*(9), 1024-1039.

Lara, P., & Romero, C. (1992). An interactive multigoal programming model for determining livestock rations: An application to dairy cows in Andalusia, Spain. *The Journal of the Operational Research Society, 43*(10), 945-953.

Lara, P. (1993). Multiple objective fractional programming and livestock ration formulation: A case study for dairy cow diets in Spain. *Agricultural Systems, 41*, 321-334.

Lara, P., & Romero, C. (1994). Relaxation of nutrient requirements on livestocks rations through interactive multigoal programming. *Agricultural Systems, 45*, 443-453.

Lazo, J. P., & Davis, D. A. (2000). Ingredient and feed evaluation. In R. R. Stickney (Ed.), *Encyclopedia of Aquaculture* (pp. 453-463). Texas: Wiley-Interscience Publication.

Longman Dictionary of Contemporary English: The Living Dictionary (New Edition). (2003). Pearson Education Limited: Essex.

López-Pujalte, C., Bote, V. P. G. and Anegón, F, d., M. (2002). A test of genetic algorithms in relevance feedback. *Information Processing and Management, 38*, 793–805

Lozano, M., Herrera, F., & Cano, R. J. (2008). Replacement strategies to preserve useful diversity in steady-state genetic algorithms. *Information Sciences, 178,* 4421–4433.

Lu, X., & Zhou, Y. (2008). A genetic algorithm based on multi-bee population evolutionary for numerical optimization. *Proceeding of the 7th World Congress on Intelligent Control and Automation* (pp. 1294). Chongqing: IEEE.

Mathison, G. W. (1998). Book reviews: Animal feed formulation: Economics and computer applications. *Animal Feed Science Technology, 70,* 169-173.

Mayr, E. (1988). *Toward a new philosophy of biology: Observations of an evolutionist*. Cambridge, MA: Belknap.

McCall, J. (2005). Genetic algorithms for modelling and optimisation. *Journal of Computational and Applied Mathematics, 184*, 205-222.

Michalewicz, Z. (1994). *Genetic algorithms+data structures=evolution programs* (2nd ed.). New York: Springer-Verlag Berlin Heidelberg.

Michalewicz, Z. (2000a). Hybrid methods. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.),*Evolutionary computation 1: Basic algorithms and operators* (pp. 124-126). Bristol and Philadelphia: Institute of Physics Publishing.

Michalewicz, Z. (2000b). Introduction to constraint-handling techniques. In T. Bäck, D. B. Fogel, & Z. Michalewicz(Eds.),*Evolutionary Computation 2: Advanced algorithms and operators* (pp. 38-40). Bristol and Philadelphia: Institute of Physics Publishing.

Michalewicz, Z. (2000c). Repair algorithms. In T. Bäck, D. B. Fogel, & Z. Michalewicz(Eds.),*Evolutionary Computation 2: Advanced algorithms and operators* (pp. 38-40). Bristol and Philadelphia: Institute of Physics Publishing.

Michalewicz, Z.,& Schoenauer, M. (1996). Evolutionary algorithms for constrained parameter optimization problems. *Evolutionary Computation, 4*(1), 1–32.

Ministry of Agriculture, Food and Rural Affairs. (2008). Retrieved on September 26, 2012, from http://www.omafra.gov.on.ca/english/livestock/dairy/facts/08-039.htm.

Mitani, K., & Nakayama, H. (1997). A multiobjective diet planning support system using the satisficing trade-off method. *Journal of Multi-Criteria Decision Analysis, 6*, 131-139.

Mitchell, M. (1996). *An introduction to genetic algorithms.* London: The MIT Press.

Mohd Noor, N., Abdul Rahman, S., & Sulaiman, N. S. (2007). Meal planning model for nursery. Unpublished technical report, Universiti Utara Malaysia.

Mohd Razali, S. N. A. (2011). *Menu planning system for Malaysian boarding school using self-adaptive hybrid genetic algorithms*. Unpublished doctoral thesis, Universiti Utara Malaysia.

Mohr, G. M. (1972). The bulk constraint and computer formulations of least-cost feed mixes. *Review of Marketing and Agricultural Economics, 40* (1), 15-28.

Moraes, L. E., Wilen, J. E., Robinson, P. H., & Fadel, J. G. (2012). A linear programming model to optimize diets in environmental policy scenario. *Journal of Dairy Science, 95*, 1267-1282.

Munford, A. G. (1989a). A microcomputer system for formulating animal diets which may involve liquid raw materials. *European Journal of Operational Research, 41*, 270-276.

Munford, A. G. (1989b). Evaluating marginal costs associated with ratio and other constraints in Linear Programmes. *Journal of the Operational Research Society, 40*(10), 933-935.

Munford, A. G. (1996). The use of iterative linear programming in practical applications of animal diet formulation. *Mathematics and Computers in Simulation, 42*, 255-261.

National Research Council (NRC). (1982). *Nutritional data for United States and Canadian feeds (Third Revision): Unites States-Canadian tables of feed composition.* Washington, D. C.: The National Academic Press.

National Research Council (NRC). (2011). *Nutrient requirements of fish and shrimp.* Washington, D. C.: The National Academic Press.

Neumann, C., Harris, D. M., & Rogers, L. M. (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research, 22*, 193-220.

Nijkamp, P., & Spronk, J. (1978). Interactive multiple goal programming. *Report for the 7th meeting of the EURO-working group "Aide a la decision multicritere".* Retrieved on Jun 2, 2012, from Erasmus University Rotterdam.

Nguyen, T. T., Bouvarel, I., Ponchant, P., & van der Werf, H. M. (2012). Using environmental constraints to formulate low-impact poultry feeds. *Journal of Cleaner Production, 28*, 215-224.

Nott, H., & Combs, J. F. (1967). Data processing feed ingredient composition data. *Feed Stuffs, 39 (41)*, 21-22.

O'Connor, J. D., Sniffen, C. J., Fox, D. G., & Miligan, R. A. (1989). Least cost dairy cattle ration formulation model based on the degradable protein system. *Journal of Dairy Science, 72*, 2733-2745.

Oishi, K., Kumagai, H., & Hirooka, H. (2011). Application of the modified feed formulation to optimize economic and environmental criteria in beef cattle fattening systems with food by-products. *Animal Feed Science and Technology, 165,* 38–50.

Oloronfemi, T. O. S. (2007). Linear programming approach to least-cost ration formulation for poults. *Information Technology Journal, 6, 294-299.*

Oujifard, A., Seyfabadi, J., Kenari, A. A., Rezaei, M. (2012). Growth and apparent digestibility of nutrients, fatty acids and amino acids in Pacific white shrimp, *Litopenaeus vannamei*, fed diets with rice protein concentrate as total and partial replacement of fish meal. *Aquaculture*, *342–343,* 56–61.

Pan, W-T. (2012). A new fruit fly optimization algorithm: Taking the financial distress model as an example. *Knowledge-Based System, 26,* 69-74.

Pascual, C., Zenteno, E., Cuzon, G., Suárez, J., Sánchez, A., & Gaxiola, G. (2004). Litopenaeus vannamei juveniles energetic balance and immunological response to dietary proteins. *Aquaculture, 239*, 375-395.

Pathumnakul, S., Ittiphalin, M., Piewthongngam, K., & Rujikietkumjorn, S. (2011). Should feed mills go beyond traditional least cost formulation? *Computers and Electronics in Agriculture, 75*, 243-249.

Peña, T., Lara, P., & Castrodeza, C. (2009). Multiobjective stochastic programming for feed formulation. *The Journal of the Operational Research Society, 60*(12), 1738-1748.

Pesti, G. M., & Miller, B. R. (1993). *Animal feed formulation: Economics and computer applications.* New York: Chapman & Hall.

Pesti, G. M., & Seila, A. F. (1999). The use of an electronic spreadsheet to solve linear and non-linear "stochastic" feed formulation problems. *Journal of Applied Poultry Research, 8*(1), 110-121.

Pierre, N. R. S., & Harvey, W. R. (1986). Incorporation of uncertainty in composition of feeds into least-cost ration models. *Journal of Dairy Science, 69*, 3051-3062.

Piyaratne, M. K. D. K., Dias, N. G. J & Attapattu, N. S. B. M. (2012). Linear model based software approach with ideal amino acid profiles for least-cost poultry ration formulation. *Information Technology Journal, 11*(7), 788-793.

Polimeno, F., Rehman, T., Neal, H., & Yates, C. M. (1999). Integrating the use of linear and dynamic programming methods for dairy cow diet formulation. *The Journal of the Operational Research Society, 50*(9), 931-942.

Pomar, C., Dubeau, F., Létourneau-Montminy, M. P., Boucher, C., & Julien, P.-O. (2007). Reducing phosphorus concentration in pig diets by adding an environmental objective to the traditional feed formulation algorithm. *Livestock Science, 111*, 16-27.

Poojari, C. A.,& Varghese, B., (2008). Genetic algorithm based technique for solving chance constrained problems, *European Journal of Operational Research, 185*, 1128-1154.

Prékopa, A. (2003). Probabilistic programming. In Ruszczynski, A. & Shapiro, A. *Handbooks in OR and MS* (Vol. 10, pp. 267-351). North Holand: Elsevier Science.

Qing-dao-er-ji, R.,& Wang, Y. (2012). A new hybrid genetic algorithm for job shop scheduling problem. *Computers & Operations Research, 39*, 2291–2299.

Rahman, S. A., & Bender, F. E. (1971). Linear programming approximation of least-cost feed mixes with probability restrictions. *American Journal of Agricultural Economics, 53*, 612-618.

Ramli, R. (2004). An evolutionary algorithm for the nurse scheduling problem with circadian rhythms. Unpublished doctoral thesis, Universiti Sains Malaysia, Malaysia.

Randly, H. L, & Sue, H. E. (1998). Practical genetic algorithms. USA: A Willey-Interscience Publication.

Rehman, T., & Romero, C. (1984). Multiple-criterion decision making techniques and their role in livestock ration formulation. *Agricultural Systems, 15*(1), 23-49.

Rehman, T., & Romero, C. (1987). Goal programming with penalty functions and livestock ration formulation. *Agricultural Systems, 23*, 117-132.

Render, B., Stair, J., R. M., & Hanna, M. E. (2006). *Quantitative analysis for management* (9th ed.). Upper Saddle River, New Jersey: Pearson Education, Inc.

Romero, C., & Rehman, T. (2003). Livestock ration formulation via goal programming with penalty functions. In Romero, C. & Rehman, T. *Multiple criteria analysis for agricultural decisions* (Vol. 11, pp. 149-161).

Rossi, A., & Boschi, E. (2009). A hybrid heuristic to solve the parallel machines job-shop scheduling problem. *Advances in Engineering Software, 40*, 118-127.

Roush, W. B., Stock, R. H., Cravener, T. L., & D'Alfonso, T. H. (1994). Using chance-constrained programming for animal feed formulation at Agway. *Interfaces. The Institute of Management Sciences, 24*, 53-58.

Roush, W. B., Cravener, T. L., & Zhang, F. (1996). Computer formulation observations and caveats. *Journal of Applied Poultry Science, 5*, 116-125.

Roush, W. B., & Cravener, T. L. (2002). Stochastic true digestible amino acid values. *Animal Feed Science and Technology, 102*, 225-239.

Roy, L. A., Davis, D. A., Saoud, I., P., & Henry, R. P. (2007). Effects of varying levels of aqueous potassium and magnesium on survival, growth, and respiration of the Pacific white shrimp, Litopenaeus vannamei, reared in low salinity waters. *Aquaculture, 262,* 461-469.

Şahman, M. A., Çunkaş, M., İnal, Ş., İnal, F., Coşkun, B., & Taşkiran, U. (2009). Cost optimization of feed mixes by genetic algorithms. *Advances in Engineering Software, 40*, 965-974.

Salcedo-Sanz, S. (2009). A survey of repair methods used as constraint handling techniques in evolutionary algorithm. *Computer Science Review, 3*, 175-192.

Saxena, P., & Chandra, M. (2011). Animal diet formulation models: A review (1950-2010). In D., Hemming. *CAB reviews: Perspectives in agriculture, veterinary science, nutrition and natural resources* (1-9). UK: CABI.

Saxena, P. (2011). *Animal diet formulation using nonlinear programming: an innovative approach. Germany*: Lambert Academic Publishing.

Shang, Y. C. (1986). Research on aquaculture economics: A review. *Aquacultural Engineering, 5*, 103-108.

Shang, Y. C., Leung, P. & Ling, B-H. (1998). Comparative economics of shrimp farming in Asia. *Aquaculture, 164, 183-200.*

Sharief, S., Eldho, T., & Rastogi, A. (2008). Elitist GA based evolutionary algorithm for groundwater contaminant remediation using pump and treat method. Proceedings of The *12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG)* (pp 2505-2512). Goa, India.

Shiau, S-Y. (1998). Nutrient requirement of penaeid shrimps. *Aquaculture, 164,* 77-93.

Smith, A. E., & Coit, D. W. (2000). Penalty functions. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary Computation 2: Advanced algorithms and operators* (pp. 41-48). Bristol and Philadelphia: Institute of Physics Publishing.

Sirisatien, D., Wood, G. R., Dong, M., & Morel, P. C. H. (2009). Two aspects of optimal diet determination for pig production: Efficiency of solution and incorporation of cost variation. *Journal of Global Optimum, 43*, 249-261.

Sivanandam, S. N., & Deepa, S. N. (2008). *Introduction to genetic algorithms*. New York: Springer.

Sivaraj, R., & Ravichandran, T. (2011). A review of selection methods in genetic algorithm. *International Journal of Engineering Science and Technology*, *3*, 3792-3797.

Spears, W. M. (2000). Recombination parameters. In T. Bäck, D. B. Fogel, & Z. Michalewicz (Eds.), *Evolutionary Computation 2: Advanced algorithms and operators* (pp. 38-40). Bristol and Philadelphia: Institute of Physics Publishing.

Spears, W. M. & De Jong, K. A. (1991). An analysis of multi-point crossover. In J. G. E. Rowlins (Eds.), *Foundations of genetic algorithms.* (pp. 301-315). San Francisco: Morgan-Koufmann.

Spronk, J. (1981). *Interactive multiple goal programming: Applications to financial planning.* Boston: Martinus Nijhoff Publishing.

Sung, S. K., II-Hwan, K., Mani, V., & Hyung, J. K. (2008). Real-coded genetic algorithm for machining condition optimization. *International Journal of Advanced Manufacturing and Technology, 38*, 884-895.

Swanson, L. W., & Woodruff, J. G. (1964). A sequential approach to the feed-mix problem a sequential approach to the feed-mix problem. *Operations Research, 12* (1), 89-109.

Tacon, A. G. J. (1990, November). Fish feed formulation and production, *Report for the Project Fisheries Development in Qinghai Province.* Retrieved on March 31, 2012, from Food and Organization (FAO) Corporate Document Repository.

Tacon, A. G. J., Cody, J. J., Conquest, L. D., Divakaran, S., Forster, I. P., & Decamp, O. E. (2002). Effect of culture system on the nutrition and growth performance of Pacific white shrimp Litopenaeus vannamei (Boone) fed different diets. *Aquaculture Nutrition, 8*, 121-137.

Talbi, E-G. (2009). *Metaheuristics: from design to implementation*. New Jersey: John Wiley & Sons.

Taylor III, B. W. (2007). *Introduction to management Science.* New Jersey: Pearson Education.

Teufel, N., Markemann, A., Kaufmann, B., Zárate, A. V., & Otte, J. (2006). *Livestock production systems in South Asia and the Greater Mekong Sub-Region:A quantitative description of livestock production in Bangladesh, Cambodia, India, Lao PDR, Nepal, Pakistan, Sri Lanka, Thailand, and Viet Nam. Rome*: Food and Agriculture Organization.

Thammaniwit, S. & Charnsethikul, P. (2013). Bender's decomposition method for a large two-stage linear programming model. *International Transaction Journal of Engineering, Management and Applied Sciences and Technologies, 4*(4), 253-268.

Thomson, E., & Nolan, J. (2001). UNEForm: A powerful feed formulation spreadsheet suitable for teaching or on-farm formulation. *Animal Feed Science and Technology, 91*, 233-240.

Tozer, P. R. (2000). Least-cost ration formulations for holstein dairy heifers by using linear and stochastic programming. *Journal of Dairy Science, 83*, 443-451.

Tozer, P. R., & Stokes, J. R. (2001). A multi-objective programming approach to feed ration balancing and nutrient management. *Agricultural Systems, 67*(3), 201-215.

Udo, I. U., Ndome, C. B.,& Asuquo, P. E. (2011a). Use of stochastic programming in least-cost feed formulation for African catfish (*clarias gariepinus*) in semi-intensive culture system in Nigeria. *Journal of Fisheries and Aquatic Science, 6, 447-455.*

Udo, I. U., Ndome, C. B., Ekanem, S. B. & Asuquo, P. E. (2011b). Application of linear programming technique in least-cost ration formulation for African Catfish (*Clarias gariepinus*) in semi-intensive culture system in Nigeria. *Journal of Fisheries and Aquatic Science, 6, 429-437.*

van de Panne, C. V. D., & Popp, W. (1963). Minimum-cost cattle feed under probabilistic protein constraints. *Management Science, 9*(3), 405-430.

Venero, J. A., Davis, D. A., & Rouse, D. B. (2007). Variable feed allowance with constant protein input for the pacific white shrimp Litopenaeus vannamei reared under semi-intensive conditions in tanks and ponds. *Aquaculture, 269,* 490-503.

Villamide, M. J., Carobaño, R., Hernández, I., Rubio, J. M., Solis, I., Saiz, A. & Garcia, J. (2009). Evolution of a feed formulation practice in amandatory course on animal production. *Procedia Social and Behavioral Sciences, 1,* 1797-1801.

Wagner, J.,& Stanton, T. L. (2006). *Formulationg rations with the Pearson square*. Livestock series management. (Colorado University). Retrieved on December 1, 2013 from http://www.ext.colostate.edu/pubs/livestk/01618.pdf

Waugh, F. V. (1951). The minimum-cost dairy feed. *Journal of Farm Economics, 33*, 299-310.

Wilke, P., Gröbner, M., & Oster, N. (2002). A hybrid genetic algorithm for school timetabling. In B. McKay, & J. K. Slaney. *AI 2002: Advances in Artificial Intelligence* (Vol. 2557, pp. 455-464). New York: Springer Berlin / Heidelberg.

Xie, S-W., Tian, L. X., Jin, Y., Yang, H-J., Liang, G. Y., Liu, Y-J. (2014). Effect of glycine supplementation on growth performance, body composition and salinity stress of juvenile Pacific white shrimp, *Litopenaeus vannamei* fed low fishmeal diet. *Aquaculture, 418–419*, 159–164

Xu, C., Zhang, Q., Li, J., & Zhao, X. (2008). A bee swarm genetic algorithm for the optimization of DNA encoding. *The Proceedings of The 3rd International Conference on Innovative Computing Information and Control (ICICIC '08) (35).* Dalian, China.

Yang, X.-S & Deb, S. (2009). Cuckoo search via Levy flights. *The Proceedings of World Congress on Nature & Biologically Inspired Computing (NaBIC 2009)* (pp 210-214), India.

Yigit, T. (2007). Constraint-based school timetabling using hybrid genetic algorithm. In R. Basili, & M. T. Pazienza, *AI*IA 2007: Artificial intelligence and human-oriented computing* (Vol. 4733, pp. 848-855). Springer Berlin / Heidelberg.

Yu, H., Fang, H., Yao, P. & Yuan, Y. (2000). A combined genetic algorithm: simulated annealing algorithm for large scale system energy integration. *Computers and Chemical Engineering, 24,* 2023–2035.

Žgajnar, J., Juvančič, L., & Kavčič, S. (2008). *Spreadsheet tool for least-cost and nutrition balanced beef ration formulation.* Paper presented at the 16th Int. Symp. Animal Science Days, Strunjan, Slovenia.

Žgajnar, J., Juvančič, L., & Kavčič, S. (2009a). Combination of linear and weighted goal programming with penalty function in optimisation of a daily dairy cow ration. *Agricultural Economics, 55*(10), 492-500.

Žgajnar, J., Juvančič, L., & Kavčič, S. (2009b). Multi-goal pig ration formulation; Mathematical optimization approach. *Agronomy Research, 7*(2), 775-782.

Zhang, F., & Roush, W. B. (2002). Multiple-objective (goal) programming model for feed formulation: An example for reducing nutrient variation. *Poultry Science, 81*, 182-192.

Zhang, F. (1999). Stochastic models and software design for feed formulation. Unpublished doctoral thesis, The Pennsylvania State University.

Zhang, W., Xu, W.,& Gen, M. (2013). Multi-objective evolutionary algorithm with strong convergence of multi-area for assembly line balancing problem with worker capability. *Procedia Computer Science, 20, 83-89.*

Zhao, N., Wu, Z., Zhao, Y.,& Quan, T. (2010). Ant colony optimization algorithm with mutation mechanism and its applications. *Expert Systems with Applications, 37*, 4805–4810.

Zioganas, C. (1981). *The determination of viable, parity and optimum sizes of family-type sheep farms in the Epirus Region of Greece.* Unpublished doctoral thesis, Wye College-University of London.