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Rendering Koi Carp and Creating Economic Value by Making Pet Food

A thesis

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Jiaoying Wei



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Abstract

Koi carp is an invasive species fish in New Zealand that severely destroys the aquatic environment in the waterways in the Waikato region. The aim of the project was to look for a method that could make use of captured koi carp. Wet rendering and autoclave rendering was examined for producing fish meal and oil under different processing conditions such as time, temperature and water content.

The water content of raw minced fish was around 69-77%, the solids content was between 23%-31%. Ash content was 6.2-7.4% of the dry solids and fat content between 13.7%-30%. Fish with a high fat content were females containing roe. The meal produced from wet rendering contained 22-28% solids, with 5-9% ash and 14-16% fat on a dry basis, while the stickwater contained 3% solids and 12-39% ash on a dry basis. Autoclave rendering produced a meal containing 26-30% solids, 3-5% ash and 30-31% fat on a dry basis and a stickwater containing 3.2% solids and 27-32% ash on a dry basis. Fat reduction in meal increased with rendering time for wet rendering up to 30% at 40 minutes rendering time, while only a 20% reduction in fat was achieved for autoclave rendering. Wet rendering was selected for producing meals.

Dry pet food and wet pet food was made by mixing rendered fish meal with chicken mince. The dry food was produced by baked while the wet food was produced by steaming. Taste testing showed that cats preferred wet pet food over the dry pet food. The dry pet food had a strong odour and poor palatability. Most cats in the taste testing hesitated to try or eat much of the dry food. It was hard for them to chew the nibbles. Less koi carp meal should be used to improve palatability. The majority of the wet pet food was consumed and it had a better odour.

A customer survey showed acceptance of koi carp for pet food was high. 92% of the participants felt they would buy or try later. People who have pets were more open-minded about using pet food made from koi carp.

An economic analysis showed that 165 tonnes of koi carp could be harvested per year from four Waikato lakes by Huntly, maintaining a biomass density of 140 kg/hectare, down from the current average density of around 200 kg/hectare. To

reduce the density down to 100 kg/hectare, koi carp would need to be harvested at 205 tonnes per year for the first 12 years, reducing harvesting to 170 tonnes per year after this. Wet pet food production is much more profitable than dry pet food production. The price of each 100 g can of wet pet food to break even should be around \$1.7 which is comparable to supermarket prices. This is approximately 10 times the price of dry pet food on a per kg basis. The profit made at \$2 per can at 165 tonnes of fish per year is \$408K while at 205 tonnes of koi carp the profit is \$526K. Dry pet food needs to be sold at just under \$6 per kg to breakeven at 165 tonnes of koi carp per year. This decreases with increased harvesting to \$5 per kg at 205 tonnes of koi carp per year. If the sales price of the dry pet food is \$8/kg, the profit obtained processing 165 tonnes of fish per year is \$52K, while at 205 tonnes per year, it is \$83K. Dry pet food at the supermarket retails for \$5 to \$15 per kg.

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Table of Contents

Abstract	i
Acknowledgements	iii
Table of Contents	iv
List of Figures	vi
List of Tables.....	viii
1 INTRODUCTION	1
1.1 Background.....	1
1.2 Problem Statement.....	2
1.3 Possible Uses of Koi Carp	3
1.4 Research Objectives.....	3
1.5 Outline of Thesis.....	3
2 LITERATURE REVIEW	5
2.1 Koi Carp.....	5
2.1.1 Biology of Koi Carp.....	5
2.1.2 Impact to Environment.....	7
2.1.3 Control and Eradication Methods	9
2.2 Possible Uses of Koi Carp	10
2.2.1 Food Application.....	11
2.2.2 Non-food Application	18
2.3 Rendering.....	21
2.3.1 Introduction of Rendering	21
2.3.2 Rendering System	22
2.4 Pet Food	25
2.4.1 Pet Food History.....	25
2.4.2 Nutrition of Pet Food.....	26

2.4.3	Pet Food Industry	29
2.4.4	Concluding Statement	33
3	MATERIALS AND METHODS	34
3.1	Materials	34
3.1.1	Fish.....	34
3.1.2	Chemicals	35
3.1.3	Other Materials and Equipment	35
3.2	Methods	35
3.2.1	Rendering Methods	35
3.2.2	Analytical Methods	36
3.2.3	Pet Food Making	37
3.2.4	Acceptance Survey and Taste Testing	38
4	RESULTS AND DISCUSSION.....	39
4.1	Trials	40
4.1.1	Proximate analysis of wet rendering	40
4.1.2	Wet Rendering.....	42
4.1.3	Proximate analysis of autoclave rendering.....	56
4.1.4	Autoclave Rendering.....	58
4.2	Pet food making and taste testing	71
4.3	Acceptance survey	75
4.4	Economic Profit Estimation.....	78
5	CONCLUSIONS	99
	References	101
	APPENDIX 1	112
	APPENDIX 2	116
	APPENDIX 3.....	117

List of Figures

Figure 2.1: A production line of dry pet food	31
Figure 2.2: A production line of wet pet food.....	32
Figure 2.3: Freeze-drying quail cat food.....	33
Figure 3.1: Location of Rangiriri	34
Figure 3.2: Soxhlet extraction apparatus.....	37
Figure 4.1: Red koi carp.....	39
Figure 4.2: Koi carp with roe	40
Figure 4.3: Temperature of the minced koi carp in in wet rendering	43
Figure 4.4: Minced fish and water mixture before and after heat treatment.....	44
Figure 4.5: Centrifuged rendered fish in tube	44
Figure 4.6: Dried stickwater.....	47
Figure 4.7: Ash of samples.....	47
Figure 4.8: Mass balance of wet rendering group 1 (10 min).....	50
Figure 4.9: Mass balance of wet rendering group 2 (20 min).....	51
Figure 4.10: Mass balance of wet rendering group 3 (40 min).....	52
Figure 4.11: Mass balance of wet rendering group 4 (60 min).....	53
Figure 4.12: Mass balance of wet rendering group 5 (80 min).....	54
Figure 4.13: Reduction in fat of wet rendering	56
Figure 4.14: Mass balance of autoclave rendering group 1 (90°C).....	64
Figure 4.15: Mass balance of autoclave rendering group 2 (100°C).....	65
Figure 4.16: Mass balance of autoclave rendering group 3 (110°C).....	66
Figure 4.17: Mass balance of autoclave rendering group 4 (120°C).....	67
Figure 4.18: Mass balance of autoclave rendering group 5 (130°C).....	68
Figure 4.19: Mass balance of autoclave rendering group 6 (135°C).....	69
Figure 4.20: Reduction in fat of autoclave rendering	71

Figure 4.21: Koi carp meal.....	72
Figure 4.22: Dry pet food.....	72
Figure 4.23: Wet pet food	72
Figure 4.24: Dry pet food taste testing result.....	73
Figure 4.25: Wet pet food taste testing result	73
Figure 4.26: Results of question 1, 3, 4 and 6.....	76
Figure 4.27: Result of question 2	77
Figure 4.28: Result of question 7	78
Figure 4.29: Logistic curve of koi carp.....	80
Figure 4.30: Growth rate of koi carp.....	80
Figure 4.31: Biomass of koi carp when different mass of koi carp captured per year.....	81
Figure 4.32: Gross profit of dry pet food sales price when different mass of koi carp captured	96
Figure 4.33: Cost composition of rendering koi carp and dry pet food making	96
Figure 4.34: Gross profit of wet pet food sales price when different mass of koi carp captured	97
Figure 4.35: Cost composition of rendering koi carp and wet pet food making	98

List of Tables

Table 2.1: Omega 3 fatty acids content in different carp.....	15
Table 2.2: Advantages and disadvantages of wet rendering system.....	23
Table 2.3: Comparison of batch and continuous dry rendering system.....	24
Table 2.4: Comparison of the low-temperature rendering system.....	24
Table 2.5: Advantages and disadvantages of freeze-drying.....	32
Table 4.1: Water content of the first batch of raw fish used in wet rendering.....	40
Table 4.2: Ash content of the first batch of raw fish used in wet rendering	41
Table 4.3: Fat content of the first btach of raw fish used in wet rendering	41
Table 4.4: Water content of the second batch of raw fish used in wet rendering	41
Table 4.5: Ash content of the second batch of raw fish used in wet rendering	41
Table 4.6: Fat content of the second batch of raw fish used in wet rendering.....	41
Table 4.7: Composition of raw fish used in wet rendering	42
Table 4.8: Composition of raw fish used in wet rendering on a wet basis	42
Table 4.9: Temperature of the minced koi carp in in wet rendering.....	42
Table 4.10: The ratio of koi carp to water.....	43
Table 4.11: Water content of stickwater and solids after rendering in wet rendering group 1 (10min)	45
Table 4.12: Water content of stickwater and solids after rendering in wet rendering group 2 (20min)	45
Table 4.13: Water content of stickwater and solids after rendering in wet rendering group 3 (40min)	46
Table 4.14: Water content of stickwater and solids after rendering in wet rendering group 4 (60min)	46
Table 4.15: Water content of stickwater and solids after rendering in wet rendering group 5 (80min)	46
Table 4.16: Ash content of the fish meal from wet rendering	48
Table 4.17: Ash content of stickwater from wet rendering.....	48

Table 4.18: Fat content of fish meal from wet rendering.....	49
Table 4.19: Summary results of fish and stickwater of wet rendering.....	55
Table 4.20: Water content of the raw fish used in autoclave rendering.....	57
Table 4.21: Ash content of the raw fish used in autoclave rendering	57
Table 4.22: Fat content of the raw fish used in autoclave rendering	57
Table 4.23: Composition of raw fish used in autoclave rendering	57
Table 4.24: Composition of raw fish used in autoclave rendering on a wet basis.....	57
Table 4.25: Mass of raw fish and water used in autoclave rendering	58
Table 4.26: Water content of stickwater and solids after rendering in autoclave rendering group 1 (90°C)	59
Table 4.27: Water content of stickwater and solids after rendering in autoclave rendering group 2 (100°C)	59
Table 4.28: Water content of stickwater and solids after rendering in autoclave rendering group 3 (110°C)	59
Table 4.29: Water content of stickwater and solids after rendering in autoclave rendering group 4 (120°C)	60
Table 4.30: Water content of stickwater and solids after rendering in autoclave rendering group 5 (130°C)	60
Table 4.31: Water content of stickwater and solids after rendering in autoclave rendering group 5 (135°C)	60
Table 4.32: Ash content of rendered fish in autoclave rendering	61
Table 4.33: Ash content of stickwater in autoclave rendering.....	62
Table 4.34: Fat content of rendered fish in autoclave rendering	63
Table 4.35: Summary results of fish and stickwater of autoclave rendering	70
Table 4.36: Advantages and disadvantages of dry pet food and wet pet food.....	75
Table 4.37: Reproduction of koi carp and mass of koi carp captured.....	82
Table 4.38: Weight ratio of koi carp body parts	84
Table 4.39: Parameters of rendering koi carp (edible fillet and inedible parts)	84

Table 4.40: Solids content fraction of wet meal, stickwater, chicken meal, nibbles and raw chicken breast.....	85
Table 4.41: Heat capacity of water, fish, fish meal and nibbles	85
Table 4.42: Energy price and labour cost.....	85
Table 4.43: Parameters of steaming/boiling wet pet food.....	86
Table 4.44: Working hours and labour cost.....	86
Table 4.45: Workload and cost of electrofishing boat	86
Table 4.46: Cost of edible rendering.....	86
Table 4.47: Cost of koi carp meal drying for dry pet food production	87
Table 4.48: Cost and revenue of dry pet food production.....	88
Table 4.49: Cost and revenue of crude koi carp oil	89
Table 4.50: Cost and revenue of making stickwater powder (stickwater option 1).....	89
Table 4.51: Cost of wastewater treatment of stickwater (stickwater option 2).....	90
Table 4.52: Cost of inedible koi carp parts rendering.....	90
Table 4.53: Cost and revenue of inedible koi carp parts meal drying.....	91
Table 4.54: Cost and revenue of inedible koi carp parts crude fish oil.....	91
Table 4.55: Cost and revenue of making inedible koi carp parts stickwater powder (stickwater option 1).....	92
Table 4.56: Cost of wastewater treatment of inedible koi carp parts stickwater (stickwater option 2).....	93
Table 4.57: Revenue of rendering koi carp and making dry pet food (165000 kg koi carp captured per year).....	93
Table 4.58: Cost and profit of rendering koi carp and making dry pet food (165000 kg koi carp captured per year)	93
Table 4.59: Cost and revenue of wet pet food production	94
Table 4.60: Revenue of rendering koi carp and making wet pet food (165000 kg koi carp captured per year).....	95
Table 4.61: Cost and profit of rendering koi carp and making wet pet food (165000 kg koi carp captured per year)	95

1 INTRODUCTION

1.1 Background

New Zealand separated from Gondwana 80 million years ago. In the long time of isolation, the composition of its ancestral biota, its tectonic history of changing shorelines and mountain building, and its changing climate, have all influenced the composition and distribution of its plant and animal communities (A.Coopera & R.Millenerb, 1993). Most of New Zealand's native flora and fauna are unique.

Before the arrival of humans, 80% of New Zealand was covered by forest, but now only 23% of the land is forested (Taylor & Smith). There were no large predators in New Zealand for millions of years which led to the evolution of birds which cannot fly. Pest animals and plants introduced by humans pose a serious threat to local biota. The introduced species such as rats and weasels cause the decrease of endangered birds like the kiwi and kakapo as they cannot fly and their eggs are easily obtained. But the introduction of weasels was not an accident, the original intention was controlling the pest rabbit (Thomson, 1992). However, the government has to carry out a plan to eradicate them to protect endangered local species now.

As well as the threat on land, the aquatic environment is also facing problems by introduced pest species. New Zealand has many freshwater ecosystems, including more than 70 major river systems and 770 lakes, and at least 73 significant wetlands (Cromarty, 1996). Invasive species are the key threat to freshwater ecosystems and few water bodies in New Zealand support a biota that is wholly native (Champion *et al.*, 2004; Collier *et al.*, 2015). Over 200 freshwater plant and animal species have been introduced to New Zealand. In total 49 fish species have been introduced and have established a self-sustaining population (McDowall, 1980; Champion *et al.*, 2004). Although not all of the introduced species become invasive species, many of them have the potential to become pest species.

Common pest fish species in Waikato region are koi carp, catfish, perch, and tench. Among the invasive fish community, koi carp is of the largest number. Koi carp, also called European carp or Japan koi were commonly believed to have been bred from the common carp (*Cyprinus carpio*). Although research has examined Koi

carp origins using their mitochondrial DNA (mtDNA), the genetic structure matching to the geographic populations is still not clear (Mabuchi *et al.*, 2005). Koi carp are believed to be the most undesirable and noxious pest in New Zealand. This species is thought to have been imported into New Zealand accidentally in the 1960s as part of a goldfish consignment. Wild stocks of koi carp were first found in the Waikato River in 1983. From then on, being highly adaptable and without natural predators in the rivers and lakes, the number of koi carp has increased rapidly.

1.2 Problem Statement

Koi carp is believed to be one of the most ecologically detrimental invasive freshwater fish species (A.Coopera & R.Millenerb, 1993). It invades the local fish habitat and competes for resources. Although the reproduction rate of koi carp from zero to three years of age is lower than that of the common carp in Europe, it is higher after five years of age (Tempero *et al.*, 2006). Koi carp is a highly fertile species where a mature female can produce 1000000 mature oocytes in a single breeding cycle (Brown *et al.*, 2003). Koi carp are bottom feeders, stirring up sediment, and consume a large amount of food. Disturbing the sediment increases the water turbidity and nutrient concentrations in the aquatic system, making the water quality worse (Viswam, 2010). It poses a great threat to the survival of native fish.

Eradication of koi carp is underway to stop koi from destroying the aquatic ecosystem and endangering native fish species. Fishing methods include boat electrofishing, fyke (a bag net for catching fish) netting, automated feeder-traps and beach seining (a fishing net that hangs vertically in the water with floats at the top and weights at the bottom edge)(Tempero, 2015).

Although a large amount of koi carp is captured every year, it poses another problem - how to make use of the fish. Because of the bony nature of the fish and earthy taste, the acceptance of koi carp in the diet is low in New Zealand and most western countries. Therefore, to consume the captured fish as human food is not viable. Commonly, the captured fish is killed and discarded, but the fish itself is heavy-bodied, oily and nutritious. It is better to couple eradication with methods of using these koi carp, thus reducing waste and offsetting the eradication costs.

However, there is still no appropriate method for koi carp use that has been put into practice.

1.3 Possible Uses of Koi Carp

Using koi carp directly as human food is common in some Asian countries. The composition of koi carp from Viswam (2010) by wet rendering was 71.5% moisture, 24.9% protein, 1.4% lipid and 2.2% ash. It is a good resource for protein and eating them is the most simple and direct way of making use of them. There are many varieties of food containing fish in the market, such as fish sausages and fish patties. Other fish products like fish oil and gelatin are extracted from various fish species. Mostly, these products are made from marine fish but they still give examples for using koi carp. As the number of people raising pets increase, the demand for pet food increases as well. Some pet foods contain fish to balance nutrition in pet diets, mainly because the unsaturated fatty acids contained in other food in both human and pet diets is very low, but it is rich in fish sources. It is possible to add koi carp in pet food but its acceptance by both pets and people needs to be investigated. Alternative uses of fish is for fish silage, bio-fertilizer, biogas production and bio-plastics. However, all the above have not been made use of koi carp as a potential source. To make use of koi carp, market viability, product acceptability and the nature of the fish must be taken into account.

1.4 Research Objectives

- Separate koi carp components by wet rendering and autoclave rendering under different conditions, including time and temperature, to determine yields of oil and meal.
- Making dry pet food with koi carp fish meal
- Making wet pet food with koi carp
- Investigation of acceptance as a pet food by consumers
- Investigation of acceptance as a pet food by pets

1.5 Outline of Thesis

Chapter 2 is the literature review chapter and will include the introduction of koi carp, options for using koi carp, rendering methods and pet food. The aims of the research will be presented at the end of Chapter 2. Materials and methods will be

presented in Chapter 3 including wet rendering and autoclave. Both of the two rendering methods will contain experiments under different conditions. Processing of making pet food will be included in Chapter 3, including dry and wet pet food. Results and discussion will be presented in Chapter 4 with the results of trials, acceptance survey and economic profit estimation. Finally, the conclusions will be shown in Chapter 5.

2 LITERATURE REVIEW

2.1 Koi Carp

2.1.1 Biology of Koi Carp

Koi carp is the ornamental species of common carp, *Cyprinus carpio* L. The common carp, *Cyprinus carpio*, can be divided into at least two subspecies: *C. c. carpio* in Europe and *C. c. haematopterus* in East Asia. The common carp, *Cyprinus carpio* L., belong to the family Cyprinidae, carps and minnows (Kojlmann, 2015). The family Cyprinidae is one of the world's major fish families with up to 1500 species (McDowall, 2010). According to McDowall (2010) this family is naturally found in North America, Asia, Europe and Africa, but absent from South America, Australia and New Zealand. It is now an invasive fish in Australia and New Zealand. Koi carp can grow up to 700 mm long and weigh up to 60 kg (Pinto *et al.*, 2005), and 1200 mm and 60 kg in R.M. McDowall's record (McDowall, 1980) which is more credible in New Zealand. The wild ancestor of the common carp originated in the Black, Caspian and Aral sea drainages and dispersed east into Siberia and China and west as far as the Danube River (K.Balon, 1995). It is represented today by the uncertain east Asian subspecies *Cyprinus carpio haematopterus* and by the east European *Cyprinus carpio carpio* (K.Balon, 1995). Koi carp in New Zealand is also known as European carp by (McDowall, 1980; Collier *et al.*, 2015), however, research has proved that there is a large genetic distance between European carp and East Asia carp (Kohlmann & Kersten, 1999; Gross *et al.*, 2002; Zhou *et al.*, 2003; Kohlmann & Kersten, 2013) and that koi carp is an offshoot of the East Asia carp.

Koi carp resemble goldfish, but with a more pointed snout and a pair of small barbels on the corners of the mouth (McDowall, 1980). The common colours of koi carp are orange, yellow, black, red or white. Because of the variety colours, koi carp became a 'koi hobby' internationally at one time. It was estimated that the period of the 'serious koi hobbist' in Japan was from 1965 to 1990 and peaked in 1978 (Kock & Gomelsky, 2015). It coincides with the time that is believed to be the period when the koi carp were introduced to New Zealand.

Koi carp are covered by large colourful cycloid scales over the whole body with the exception of the head which is scaleless. From a genetic perspective, there are four types of scale cover on koi carp. The type is determined by an interaction of two genes having two alleles each (S/s and N/n) (Kojlmann, 2015):

- a) Scaled carp, homozygous $SSnn$ or heterozygous $Ssnn$,
- b) Mirror carp, recessive homozygous $ssnn$,
- c) Linear carp, heterozygous $SSNn$ or $SsNn$,
- d) Leather or naked carp, heterozygous $ssNn$.

Colours of koi carp are controlled by pigment cells in the skin. Erythrophores, xanthophores, melanophores, leucophores and cyanophores are the five skin pigments that determine the red, yellow, black, white and blue shades. Iridophores are the special one that contain iridescent plate-like crystals of guanine resulting in a shiny, metallic appearance of the skin (Kock & Gomelsky, 2015). In combination with yellow pigment, the effect can be golden and with white it can be silver (Kock & Gomelsky, 2015). It was suggested that there was also an allele determining the presence of melanin in the lower skin layer (Katassonov *et al.*, 2001) which influences the background colour of fish.

Koi carp investigated in New Zealand can live up to 12 years and most are females, while males rarely live in excess of 8 years (Tempero *et al.*, 2006). Under natural conditions, the possible longest lifespan for koi carp is 15 years (Vilizzi & Walker, 1999). The growth rate of koi carp is relatively slow in the first three years in New Zealand compared to the growth rate in Europe and Australia (Tempero *et al.*, 2006). But after five years koi carp growth rate in Europe is slower than in New Zealand, while Australia is still higher (Tempero *et al.*, 2006). From research on carp populations around the world, sexual maturity and growth rate of koi carp are relative to temperature and latitude, while growth rates for carp in temperate latitudes are very variable (Tempero *et al.*, 2006; Oyugi *et al.*, 2011). Adult wild carp typically become sexually mature at two to three years old for females and one to two years for males (Hicks & Ling, 2015).

As a member of family Cyprinidae, koi carp have much stronger fecundity than many other native fish. Carp in temperate latitudes begin to spawn in spring when the water temperature rises above about 17°C (Hicks & Ling, 2015). Relative

fecundity was found to be around 200000 with a mean of 100000 offspring per female (Brown *et al.*, 2003; Tempero *et al.*, 2006). Anywhere between 0.1 million to 1 million eggs per kg are produced in an oogenetic cycle or a year. In some warm environment, females have the potential to spawn repeatedly but the number of eggs released per cycle is lower (Linhart *et al.*, 1995; Brown *et al.*, 2003; Tempero *et al.*, 2006). According to Brown *et al.* (2003), the fecundity of the female and egg size are positively proportional to maternal size but not age. That means even old female koi carp have high fecundity. The egg has a relatively thick vitelline envelope or zona radiata which is reorganized into the fertilization envelope after fertilization (Linhart *et al.*, 1995). Fertilization rate of the eggs was observed by Linhart *et al.* (1995) and Bozkurt and Ogretmen (2012) to be ranging from 67% to 80% and reduces overtime after spawning. The high fecundity makes carp one of the most competitive fish species in water ways and they dominate many aquatic ecosystems in Waikato region, New Zealand.

Carp undergo seasonal movements through warm water during winter and summer. They also move from upstream to downstream floodplains to lay eggs in shallow water bodies. The fry also moves to the downstream floodplains as large amount of larval native and nonnative fish are found in floodplains of the lower Waikato River (Wu *et al.*, 2013).

2.1.2 Impact to Environment

Carp are a super invader in temperate countries with mild climates such as South Africa, Australia, and New Zealand, partly because they are limnophilic (thrive in lakes and ponds), euryhaline (tolerant of a wide range of salinity), eurythermal (tolerate of a wide range of temperatures), tolerant of high turbidity, and are resistant to hypoxia (as low as 15% oxygen saturation) (Collier *et al.*, 2015; Hicks & Ling, 2015). They can survive a wide range of temperatures from freezing water to up to 43°C, although optimal temperatures for growth are 27-32°C (Collier *et al.*, 2015).

Like many other fish species, koi carp diet and feeding habits change during different growth stages. The size of the food they eat is related to their body size. Only slow and immobile food particles with a diameter up to 4% of the carp's body length are effectively processed. Carp larvae initially feed endogenously from the remains of the egg yolk (Huser Brian & Pia, 2015). Zooplankton is the most

important food resource for carp fry (Huser Brian & Pia, 2015). Adult carp diet has been demonstrated to be exceptionally diverse including phytoplankton, zooplankton, pelagic invertebrates, macrobenthos, plant material such as seeds and leaves, detritus, fish eggs, and in some cases fish (Huser Brian & Pia, 2015). Adult carp have an entirely different way of preying, using their barbels to detect food in the sediment. Carp dig intensively in the sediment, using their nose to separate stones and other non-digestible items and then put their mouth over organisms and suck them up (Kock & Gomelsky, 2015). Muscular cushions in the pharyngeal roof (palatal organ) and floor (postlingual organ) permit post-capture selection between food and non - food and transport (Sibbing F.A. *et al.*, 1986). This eating mechanism stirs up the sediment increasing turbidity of the water, reducing water quality.

From Scheffer *et al.* (1993), shallow lakes can have two alternative equilibria: a clear state dominated by aquatic vegetation, and a turbid state characterized by high algal biomass. Aquatic macrophytes immobilize sediment on the bottom of the lake. The sediment layer is relatively stable that has little contact with the upper layers. However, carp expand this zone by increasing the sediment mixing depth (Huser *et al.*, 2016) and make it more unstable by their foraging. This becomes the main resource of bioturbation and increases water turbidity. Carp influence the submerged macrophytes and therefore turbidity of water in many ways. When carp are selecting food in the mud, it is generally agreed that carp destroy the aquatic vegetation by uprooting plants (Crivelli, 1983). Although not all macrophyte taxa are affected by carp burrowing (Huser Brian & Pia, 2015), the taxa that resist it are not widely spread in most water bodies. Species like the white water lily, which has large rhizomes, are more likely to survive carp foraging but most macrophytes have weaker root systems and are more susceptible (Roberts *et al.*, 1995). As the macrophytes disappear, more sun light can penetrate deeper into the water and provide energy for phytoplankton. The mass of phytoplankton grows fast and the water body becomes eutrophic with high turbidity and unpleasant colour and smell. From another aspect, with the disappearance of macrophytes, the influence of wind on turbidity is strengthened. The switch of a water body from a clear to turbid state only occurs once the carp biomass density exceeds a critical threshold (Driver *et al.*, 2005).

Carp alter the chemistry of aquatic systems, both in the water column and at the sediment water interface (Huser Brian & Pia, 2015). Carp feeding activity strongly mixes the sediment with the water exposing the sediment to oxygen, leading to increased mineralization of organic matter previously buried in the anoxic sediment layers (Ritvo *et al.*, 2004), which may decrease the oxygen concentration. The mixed and resuspended organic components provide phytoplankton nutrients facilitating their growth. The oxygen released by phytoplankton will increase during day time. However, zooplankton and bacterioplankton that feed on phytoplankton increase as well and consume oxygen. The pH value of water may change due to the consumption of carbonic acid (H_2CO_3) because of the growth of phytoplankton biomass, also known as dissolved CO_2 (Huser Brian & Pia, 2015).

Carp contribute to water body nutrient loads directly through excretion and indirectly through feeding activity (Collier *et al.*, 2015). Nutrients like phosphorus and nitrogen in excrement affect the growth of some microorganisms such as cyanobacteria (Havens *et al.*, 2003). The dietary preference of adult carp has substantial effects for invertebrates, as they will consume a large number of invertebrates. On the other hand, they cannot eat macroinvertebrates due to their size. This acts as a screen for invertebrate species. The effects carp have on microorganism and invertebrates are complicated and variable due to differing carp population sizes, ages and ecosystem structures (Huser, Brian & Pia, 2015).

2.1.3 Control and Eradication Methods

Piscicides, as a chemical method of eradication, can be divided into two categories: (i) specific compounds with some species selectivity; and (ii) treatments that kill all freshwater life in the treated area (West, 2015). Lime is obviously the second kind. Drainage is always used to drop water level and increase lime concentration in small ponds. Lime was immediately replaced by rotenone as lime can kill a wide range of aquatic organisms with the pH in the ponds reaching greater than 12 for four to five days (West, 2015). Rotenone is very toxic to fish but is not harmful to other organisms and breaks down quickly. However, rotenone is expensive and has other limitations:

- Time to degrade: It takes a shorter time for rotenone to degrade than many other piscicides but it still takes up to 10 days when rotenone loses its toxicity (New Zealand Department of Conservation, 2003).

- Affects a wide ranges of fish species: Although efficacy to fish is not the same, rotenone kills without selection. Some invasive fish like catfish has higher resistance to rotenone than native fish.
- Not efficient in cold water, deep water and turbid water: Temperature and turbidity influence the spread of rotenone. Rotenone needs to be well mixed throughout the water column (New Zealand Department of Conservation, 2003). This is feasible in shallow water body.
- May cause disease: Rotenone is a possible trigger that causes a syndrome in rats that looks, both behaviorally and neurologically, very much like Parkinson's disease (Helmuth, 2000). But it has not been reliably implicated as a risk factor. Although there is currently little scientific basis, the possibility of the link would preclude approval of using rotenone in any water used for drinking propose (New Zealand Department of Conservation, 2003).

To avoid potential risks, protect other fish species and save money, physical methods are widely used in New Zealand. Screens and barriers like carp separation cages, exclusion screens, nets and one-way barriers are installed to limit the movement of pest fish and prevent them escaping to another waterway (David, 2015). Boat electrofishing, fyke netting, automated feeder-traps and beach seining have been used in Lake Ohinewai (Tempero, 2015). The only electrofishing boat in New Zealand is run by The University of Waikato and was built based on the experience of Australian fishery researchers (Hicks *et al.*, 2015). A pulsator consisting of a set of electrodes before boat is set to a range of different voltages with poled direct current and a frequency of 60 Hz (Hicks *et al.*, 2015). It induces fish to swim forward anode and fall into narcosis and tetany (Hicks *et al.*, 2015). Then it is easier to catch them by net.

2.2 Possible Uses of Koi Carp

As an invasive species, the koi carp or common carp (*Cyprinus Carpio*) captured must be killed in New Zealand. But currently, other than composting, there is not method for using the captured fish. Koi carp are oily and nutritious. They contain more than 20% protein and around 1.4% lipid and can be a good resource of protein for various industries such as aquaculture and pet food.

2.2.1 Food Application

- ***Fresh fish***

Fish and fish products trade is one of the most traded products worldwide. In 2016, the fish product reached a peak of 171 million tonnes, of which 88% was directly consumed by human (FAO, 2018). 35% of the fish product was traded internationally (FAO, 2018).

Fish is a good protein resource. Fish contains easy-digested, low-level calories and high-quality protein which can provide 50 to 60% of an adult's daily protein requirement with 150 g fish intake (FAO, 2018). Fish is also rich in essential polyunsaturated fatty acids like docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), both of them are omega-3 fatty acids. Omega-3 fatty acids are crucial for the human central nervous system, cardiovascular health and retinal health (Carlson, 1989; Martinez, 1989). Infants consume omega-3 fatty acids both as linoleic and linolenic acids (Carlson, 1989).

In 2015, Asia consumed most of the fish worldwide with 106 million tonnes at 24.0 kg per capita (FAO, 2018). Carp are a common commercial fish in the Asian market, however common carp (*Cyprinus Carpio*) is not popular in New Zealand because of their bony nature and earthy taste.

- ***Canned fish***

Canned fish was first innovated for army food preservation by a Frenchman called Nicolas Appert in 1795. Canning the fish is a method to prevent fish spoilage thus enhance the shelf life to one or two years by packaging the fish into a can and sealing it. The can is heated with water under pressure to achieve a higher temperature than 100°C to kill spoilage bacteria in the fish, sterilizing the final product. Mostly, the raw material used in canned fish is saltwater fish such as salmon, sardine, herring, and tuna.

Canned fish is believed to be a good source of digestible proteins, fluoride, iodine, selenium, essential fatty acids, and vitamin D (Usydus *et al.*, 2008). The essential long-chain polyunsaturated fatty acids: eicosapentaenoic acid and docosahexaenoic acid are well preserved in canned fish products (Gladyshev *et al.*, 2009). The sums of these two fatty acids in canned Pacific saury (*Cololabis saira*), Pacific herring (*Clupea harengus*) and Baltic sprat (*Sprattus sprattus*) are enough to meet the

demand of human body (Gladyshev *et al.*, 2009). Mostly, the contamination occurring in canned fish products are at a low level, but the contaminants such as heavy metals and dioxin may pose problems (Usydus *et al.*, 2008). Minerals in canned silver carp have changed very little over the years except for copper which has increased substantially (Vafaei *et al.*, 2018).

Small sized fish are always canned without removing bones. Bones in canned fish products are already well cooked and fragile. Canning may be a good method to soften the bones of carp making it edible. With the addition of ingredients and dressing, the earthy taste may also be concealed. It seems possible to make canned fish with koi carp in New Zealand but no substantial research has been done yet.

- ***Dried fish***

Dried fish is another way of enhancing the shelf life of fish. Spoilage is mainly caused by spoilage bacteria and fungi. Three crucial factors are required by microorganisms to survive: water, nutrients, and oxygen (except for anaerobic bacteria). Drying is the process of removing water and controlling water activity in food. Water activity, known as a_w , is the partial vapour pressure of water in a substance divided by the standard state partial vapour pressure of water. Water activity is a factor used to determine if the environment is suitable for microorganisms to grow. Usually, a water activity below 0.91 is believed to be not suitable for the growth of bacteria and the lowest growth a_w for fungi is 0.7 (Rockland & Beuchat, 1987). Reducing the moisture content to a critical value to inhibit the growth of microorganisms is the principle of fish drying. This could be achieved by physical methods such as air drying or immobilizing the water using sugar, salt or other chemicals (e.g. pickling or brining fish) (Doe, 1998).

In the physical drying process, temperature and time will influence the drying efficiency and the quality of the product. If a rapid drying process is involved, a hard semi-impermeable pellicle will form therefore preventing further water diffusion and evaporation (Doe, 1998). Higher temperatures can accelerate the water evaporation but if the temperature exceeds 35°C, the fish will start to cook (Doe, 1998).

Commonly, cold-smoked fish is edible directly without further cooking. However, neither the smoking temperature nor the salt content can kill foodborne pathogens

(Badr, 2012). In addition, smoked fish is a food resource containing a high level of polycyclic aromatic hydrocarbons (PAHs) which are carcinogenic (Tongo *et al.*, 2017). PAHs are found in food as a result of food processing techniques like curing, drying, smoking, roasting, grilling, barbecuing and refining (Tongo *et al.*, 2017) resulting in a health risk when consuming these fish products. Therefore fish drying is not an appropriate way to make use of the carp and make them a food resource.

- ***Fish patties***

Patties are a flattened, shaped, serving of ground meat or meat alternatives with various extenders. They are precooked. It requires less time to cook them which makes patties popular in fast food restaurants.

A study (Sehgal *et al.*, 2011) showed that fish patty made from common carp (*Cyprinus carpio*) has low consumer preference due to the intramuscular spines. The size of the fish and the extender affects the texture. It was found that the patties made from fish and boiled potatoes had better texture and acceptability (Sehgal *et al.*, 2011). Cooking can decrease the crude protein and increase total soluble sugar content in fish patties and make them taste better. Heating, mincing and pressure help to soften the bones in fish. Sehgal's study gives an idea of making fish patties with the carp. It seems viable if the carp bone problem can be solved.

- ***Fish roe***

Fish roe is a nutritious delicacy. Different species of fish roe have different nutrient contents but all the fish roe are low in fat and rich in polyunsaturated fatty acids, eicosapentaenoic and docosahexaenoic acids. For example, one ounce (28.35g) of wild salmon roe contains only 4 grams of fat and 70 calories (Braverman, 2019). The fish eggs are also rich in vitamin B₁₂. Fish roe is a good resource for people who are on a diet. The famous delicacy caviar is made of sturgeon roe.

Heavy metals and other kinds of pollutants in fish roe are a problem. Hazardous chemicals accumulated in fish roe are harmful to human body. It was found that the greatest number of ¹³⁷Cs (4,5 Bq/kg) and ⁹⁰Sr (3,2 Bq/kg) were accumulated in the fish roe of perch (Bilokon *et al.*, 2013). Heavy metals (cadmium, copper, zinc, and lead), and natural radionuclides ²²⁶Ra and ²³²Th were accumulated to a greater amount in bream fish roe (Bilokon *et al.*, 2013). This could be an issue with using koi carp roe as a food resource in New Zealand.

Koi carp are high fecundity fish, therefore carp roe should be a good option for consumption. But the roe is only a part of the whole fish and is not accessible all the time. After extracting the roe, the remaining fish body needs to be processed. Making fish roe product can only be a by-product industry in combination with other methods. In addition, no research has been undertaken to investigate the contents of harmful chemicals and heavy metals in carp roe in New Zealand yet. This option alone to increase the value of carp in New Zealand seems to be infeasible.

- ***Fish oil***

Fish oil is the fat or oil that is extracted from fish tissue. It is usually extracted from oily fish like tuna. The liver is the organ that could also be used to make fish liver oil. As a health care product, the main nutrients in fish oil that help people to keep in good health are unsaturated fatty acids: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). It is well known that these omega 3 fatty acids are crucial to human body and are rich in fish tissue.

One or two portions of fish are recommended each week to provide essential nutrients. If fish is not available, fish oil products can help. The appropriate ratio of omega 6 fatty acids over omega 3 fatty acids is 3:1 where the omega 6 fatty acids usually come from the red meat.

Humans benefit from fish oil consumption. It is reported that our brain is made up of nearly 60% fat much of which are omega 3 fatty acids (Robertson, 2018). Therefore, omega 3 fatty acids are essential for normal brain function. They are particularly important for supporting pregnancy and for infants whose brains are developing (Carlson, 1989). Fish oil intake may improve attention and reduce hyperactivity in children. Omega 3 fatty acids, particularly docosahexaenoic acid (DHA), can help to ameliorate several cardiovascular risk factors, such as elevated blood pressure (Hill *et al.*, 2007). Evidence shows that increased intake of omega 3s reduce the risk of eye diseases. Many studies (Kawakita *et al.*, 2013; Kawashima *et al.*, 2016) have indicated that fish oil may also be effective in the treatment of dry eyes. The data from another study indicated that fish oil can potentially reduce inflammation, fibrosis and oxidative stress associated with chronic renal fibrosis which is a disease commonly occurring in elderly people and leads to renal failure

(Peake *et al.*, 2011). Besides this, the benefits of eating fish oil include maintaining healthy skin, reduction of liver fat and improving bone health (Robertson, 2018).

The koi carp may be a good source of fish oil which contains less cholesterol (Viswam, 2010). The amount of omega 3 fatty acids in two different carp is given below.

Table 2.1: Omega 3 fatty acids content in different carp

Species	EPA (g/100g fresh fish)	DHA (g/100g fresh fish)
Silver carp	0.187	0.246
Big head carp	0.229	0.325

Modern people attach importance to balanced diets. This provides the main impetus of the fish oil industry. It may be a good choice to produce fish oil from the koi carp. The koi carp fish oil can be a by-product made from the rendering carp.

- ***Fish collagen and gelatin***

Collagen is a robust helical protein found in animal tissue (Shamsuddin, 2013). The name collagen dates back to the 19th century from Greek which means glue, as these proteins were first to be found from which they can make gelatin (Merrett *et al.*, 2012). Collagens, as the structural building blocks of the body, making up approximately 30% of the total protein. They are found everywhere in animal tissue such as bones, tendons, cartilage, skin, and blood. The collagen family is big. Collagens in different tissues show different properties. In bones and tendons, collagen provides high strength (Khan *et al.*, 2011). Collagen in the cornea is transparent, in heart valves, it is fatigue resistant, and in renal glomeruli, it provides an excellent filtration system (Khan *et al.*, 2011).

Up to now, around 30 types of collagen have been studied. Type I collagen is the most abundant and best-studied collagen of the body. It makes up more than 90% of the organic mass of bone and is the major collagen of many tissues (Friedman & Zeni, 2012). Besides type I collagen, type II, III, IV and V collagen are also common types of collagen. The major supporting fibrillar collagens are types I, II, III which represent more than 80 – 90 percent of this protein in the body (Friedman & Zeni, 2012).

Normal collagens are stable molecules, but if they are heated in water gelatin will be produced via the partial denaturation of native collagen. During the manufacturing of gelatin, the raw material is treated with dilute acid or alkali, resulting in partial cleavage of collagen crosslinks: the structure is broken down, therefore, gelatin is formed (Schrieber & Gareis, 2007). Gelatin is one of the most popular biopolymers, it is widely used in food, pharmaceutical, cosmetic, and photographic applications because of its unique functional and technological properties. Most gelatin products now are extracted from mammalian tissue (porcine and bovine). This gives rise to constraints and skepticism among consumers due to socio-cultural and bovine spongiform encephalopathy concerns. Animal-derived collagen is frequently used in tissue engineering applications due to its biocompatibility, but there are significant concerns about the immunogenicity of xenogeneic material as well as the possibility of pathogen transmission (Merrett *et al.*, 2012).

The demand for collagen and gelatin required by the food and pharmaceutical industries is increasing. Due to the concerns about mammalian gelatin, fish gelatin seems to be a good alternative option. Fish gelatin is not a new product. It has been made since 1960 by acid extraction (Norland, 1990). Fish collagen has a lower denaturation temperature and a lower gelling temperature than mammalian collagen and gelatin. Some cold water fish gelatin has a gelling temperature below 8°C (Norland, 1990) which makes it suitable for the frozen products. However, there are constraints in producing fish gelatin. First, it is difficult to provide adequate quantities of a particular fish skin which is appropriate for extraction. Second, the property of fish gelatin varies with species. Third, the price is high. Fish gelatin is more expensive (4-5 times higher) than mammalian gelatin (Karim & Bhat, 2009).

Although, it has been found that the skin, scale, and bone of carp contain 41.3%, 1.35% and 1.06% (on the dry weight basis) of acid-soluble collagen, respectively (Duan *et al.*, 2009), the proportions of these tissues are low in a fish body. Considering the disadvantages listed above, it seems unprofitable to make fish gelatin or collagen from the carp.

- ***Animal feed***

Pets play an irreplaceable role in people's life. Keeping pets becomes more and more popular in the modern family. In New Zealand, the population of pets living

with their family is even larger than the population of people. Around 64% of families own at least one companion animal. While most of the pets are cats and dogs, there are also special pets like rodents, fish, birds and other mammals, altogether accounting for nearly 200 million pets.

Pet owners attach importance to their pet friends which promotes the development of the pet food industry and enhances the pet food market. Similar to humans, pets require dietary protein, more than what humans require, especially the cat. It was estimated that the raw fishery products directly utilized by the cat food industry equate to 2.48 million metric tons per year (De Silva *et al.*, 2008). 13.5% of the total global fish meal was consumed by pets as dry pet food other than human consumption (De Silva *et al.*, 2008). Most of the forage fish are captured from the ocean, pushing some species to extinction which traditionally feed on the captured fish. The cost of pelagic fishing is high. The cheap, easily accessible and abundant carp is a good substitute for the marine fish. Not only in New Zealand, but also in the USA, Canada, and many countries, the carp has become an invasive species and a big environmental problem. To consume the fish as pet food will be an economic method to solve the problem at the same time preserve the ocean biota.

Besides pet feed, the koi carp can be transferred to silage for feeding livestock. Silage is traditionally made from green crops. The crops are stored in a pit or silo and the bacteria present on the plants carry out fermentation, the products of which preserve the plant material from further decay and loss of nutritional value (Allaby, 2012). The silage is prepared for livestock feeding in the dry season or winter when there is not enough fresh forage. It provides better palatability and nutrients than totally dried forage grass.

Fish silage is widely used in aquatic feeds. The process is easy and low cost. The two categories are acid fish silage and fermented fish silage. They are distinguished by the different ingredients added. The raw material used is commonly fish waste or offal. After mincing, the organic acid, mineral acid or sources of carbohydrate is added. Fish silage with acid added is called acid fish silage and the type with carbohydrate added is called fermented fish silage

During silage processing, enzymes found in fish hydrolyze proteins to free amino acids and solubilize nitrogen, thus making silage an excellent source of available amino acid sources for protein biosynthesis (Vidotti *et al.*, 2003). Fish silage is

reported to have nutritional and economic benefits. But fish silage is bulky and difficult to transport and store because of the high moisture content (about 80%) (Madage *et al.*, 2015).

Research has been taken to study the fish silage made of koi carp and it shows that this method is feasible (Oulavallickal, 2010). Further studies are needed in this area to achieve the commercial use of the fish silage made of koi carp.

2.2.2 Non-food Application

- ***Bioplastic***

Plastic is one of the most commonly used materials in our daily life. Most of the plastics are petroleum-based and non-biodegradable, without appropriate disposal methods, as the plastic is non-biodegradable, plastic pollution has become a serious global environmental problem. The demand for new alternative materials is increasing.

Plastics are actually long-chain polymers. Thus, bioplastics or biodegradable films that are degradable may be prepared from natural polymers like protein. In the food industry, nearly one third of the raw materials are disposed of and wasted. The tremendous amount of food waste has become a burden for the environment and governments. If disposed of inappropriately, the food waste will pollute the soil, contaminate the underground water, emit greenhouse gases and even create an ideal breeding ground for bacteria. The food waste can be the raw material of the polyhydroxyalkanoates (PHA). PHA is one of the key elements to drive the market for biodegradable polymers (Tsang *et al.*, 2019). It has been proven to have great potential as a substitute for traditional plastics due to its biodegradability and rubbery-like properties (Tsang *et al.*, 2019). In the fish processing industry, 70% of the initial weight of the fish become fish waste which is considered to be high-quality, low-commercial-value raw material (Araújo *et al.*, 2018). The fish waste is also a potential raw material for PHA production.

In recent years, the protein-based biodegradable plastic has been well studied. Fish proteins have advantageous properties for bioplastic preparation. The fish filleting residue had high protein content, mainly myofibrillar proteins, particularly myosin and actin, which makes it an excellent raw material from which to obtain bioplastics (Araújo *et al.*, 2018). Myofibrillar proteins derived from fish processing waste can

help to form fibrous networks, increase plasticity, and elasticity, and have good properties as mechanical and gas barriers (Araújo *et al.*, 2018). However, protein-based bioplastics possess poor mechanical properties compared to conventional plastics. The main problems are that the protein-based bioplastics are highly water-sensitive, and the window of processing conditions such as temperature and composition for successful conversion into bioplastics is narrow (Sakunkittiyut *et al.*, 2013). Kraft lignin has been found to be effective to increase the window of processing conditions of fish protein-based bioplasticw (Sakunkittiyut *et al.*, 2013). Araújo *et al.* (2018) also found processing conditions that can make the bioplastic homogeneous, translucent, resistant, flexible, and easily handled.

Plant gluten can be used to make biodegradable plastic, but with poor mechanical properties. Fish scale meal has been proved to increase the tensile strength (twice higher than that of the neat wheat gluten-based bioplastic) of the wheat gluten-based bioplastics composites as a bio-filler (Thammahiwes *et al.*, 2017).

- ***Biomarker***

Biomarkers are widely used in scientific fields. A biomarker or biological marker is a biologically measurable indicator that will show different appearance or response to chemicals of some biological state or condition.

The aquatic ecosystem is important for humans, animals, and plants. To know the pollution in water, biomarkers are needed. Serious pollution in the water can be easily observed by odor and appearance, but many kinds of pollution such as trace chemicals in water cannot be seen directly. The carp can be used to monitor the condition of waterways. In Falfushynska and Stolyar (2009) research, the metallothionein (MT), glutathione levels and acetylcholinesterase (AChE) activity changed with environment. The metallothionein, catalase and lipid peroxidation, and AChE are the most sensitive biomarkers in the liver (Falfushynska & Stolyar, 2009). Pesticides like paraquat, copper sulphate and zinc chloride in water inhibit the activity of AChE in the carp (Nemcsók *et al.*, 1984). Once the activity of AChE is inhibited, the muscle loses control and lead to behavioural changes, giving a signal of water pollution.

However, there are several factors that make this utilization infeasible. First, this method cannot help to dispose the captured fish. Biomarkers require live fish.

Second, if the carp are used to test the chemicals in water, it may be more complicated than testing the chemical compounds directly from the water sample. So using the carp as biomarkers cannot solve the problem of koi carp as an invasive species.

- ***Biofuel***

Most transport fuels we use today are produced from fossil fuel which is an unrennewable resource. The fuels consumed by the transport sector take up 58% of the primary energy consumed in the world, of which 80% are fossil fuels (Escobar *et al.*, 2009). The emissions from fossil fuel burning include CO₂, oxides of nitrogen, and sulfur dioxide which aggravate the air pollution and greenhouse gas effects (Yuvaraj *et al.*, 2019). Today the world is facing the coming energy crisis and the degradation of the environment, by exploring renewable, alternative, sustainable, efficient and cost-effective energy sources promoting biofuel research.

Biofuels are liquid, gas and solid fuels produced from biomass such as organic waste, seaweed, and micro-algae (Mrad *et al.*, 2012; Yuvaraj *et al.*, 2019). In the fish industry, about 54% of the initial feedstock is waste, including offal, bones, skin/scales (Mrad *et al.*, 2012). Waste heads, bones, tail are good resources to produce fish oil, and fish oil is a promising biofuel. In 2007, biofuels took up only 1.8 % of the transport sector in the world, with the US, the EU, and Brazil being the main biofuel producers (Azapagic & Stichnothe, 2010).

It has been found that the pollutants emitted by burning biofuel is less than burning neat fossil fuel (Mrad *et al.*, 2012). The emissions such as carbon monoxide, hydrocarbons and particulate matter are decreased with the addition of fish oil (Mrad *et al.*, 2012).

As the fillets of the koi carp are separated and used, the heads, frame, and tail remained. To make use of these resources, producing biofuel from koi carp is a potential choice.

- ***Biofertilizer***

Centuries before scientific soil research began, Native Americans understood the value of fish as a fertilizer. They buried fish in the soil to support better growth of corn. Ancient Egyptians used fish fertilizer to provide plants with more nutrients. Today, biofertilizers made of fish have come into our view again. The fish fertilizer

products in the market now have three types: fish meal, fish emulsion, and fish hydrolysates.

The organic fish fertilizers are different from quick-release synthetic fertilizers. They are slow-release fertilizers that contain nutrients that must be digested and released by microorganisms, nourishing plants for a long time. The organic fish fertilizers may also provide secondary nutrients like calcium. Plants that receive a balance of primary and secondary nutrients experience strong and steady plant growth, leading to vigorous plants that can better withstand disease and pest issues (Zehnder, 2015).

The mixture of ground fishbone and plant residues have proved to be effective in increasing the yields of sweet potatoes in Indonesian (Novianantya *et al.*, 2017). The compost fertilizer also increased the starch content in the sweet potatoes (Novianantya *et al.*, 2017).

New Zealand is an environmentally friendly country. The biofertilizers produced by fish waste meet the environment conservation concept. It is a promising way to deal with all kinds of fish waste but there is not enough research around its use as a the biofertilizer. Further studies are required in the future to develop this idea.

2.3 Rendering

2.3.1 Introduction of Rendering

Each year, nearly half of the animal products are not consumed by humans. In the United States, approximately 54 billion pounds of inedible animal tissue are generated annually, which represents approximately 37 to 49 percent of the live weight of slaughtered animals (Meeker *et al.*, 2006). These by-products are highly perishable and laden with microorganisms, many of which are pathogenic to both humans and animals. Rendering is the safest, most economical method to kill the pathogenic microorganisms while reducing waste and recovering billions of dollars (Meeker *et al.*, 2006).

Rendering is a method of recycling of raw animal tissue from the slaughterhouse. It is a separation process that is used to separate animal oil to obtain products such as tallow, lard and fish oil (Carvajal *et al.*, 2015). The profitable utilization of meat industry by-products promoted the development of rendering. Wet rendering was developed in the 19th century. In the following 20th century, the batch dry rendering

appeared. To meet the demand of high efficiency, low waste during the operation and easier operation, various continuous systems were developed.

As one of the oldest recycling industries, tallow and meat meal were the main products for a long time. Inedible tallow is the main material of candle and soap making. After the twilight of the tallow candle and soap making industry, the inedible tallow and grease became a high-energy additive to livestock and poultry feed (Ockerman, 2000). In the chemicals and synthetic oils industry, tallow is increasingly used (Ockerman, 2000). Edible tallow and grease are used in cooking fats. Meat meals are widely used as a source of high protein, energy, and vitamins in animal feed. These meat meals satisfy the requirement of essential amino acids for animals. Bone meal is another important product in the rendering industry. Sufficient calcium content and other mineral content make the bone meal a good choice for poultry feed and plant fertilizers (Ockerman, 2000). However, while feeding animals with animal meal is profitable, bovine spongiform encephalopathy (BSE) is spread by feeding ruminant animals with ruminant animal products, particularly those derived from the brain and spine. Although, rendering offers a safe and integrated system of animal raw material handling and processing that complies with all of the fundamental requirements of environmental quality and disease control, proteins called “prions” which lead to BSE cannot be inactivated during the rendering process (Ockerman, 2000; Meeker *et al.*, 2006). Feeding protein supplements derived from ruminants to ruminants is banned in many countries to avoid the spread of the BSE.

2.3.2 Rendering System

Rendering is a process involving both physical and chemical transformations of animal residue by the application of heat, drying, and the separation of fat (Leon *et al.*, 2018). There are many rendering systems differing slightly from others. From the different moisture content during the process, rendering systems can be divided into wet and dry systems. Rendering systems can be divided into two categories: batch systems and continuous systems. Temperature and the time of heating are critical factors that affect the quality and quantity of the products (Pérez - Calvo *et al.*, 2010).

The rendering system which involves water being added to the raw material is called wet rendering. In wet batch rendering system, steam or water is injected

directly into the container to heat the material. In the batch system which is known as autoclave rendering, the temperature can reach 140°C at pressures around 361 kPa (Ockerman, 2000). The treatment lasts for three to four hours. During the process, the pressure is slowly reduced to atmospheric pressure. Then the solubilised fat is drained off, the material is pressed or centrifuged to separate the remained water and oil. The defatted material is dried by evaporation or thermal treatment. The advantages and disadvantages of the wet rendering system are given in Table 2.2.

In dry batch rendering systems, the material is indirectly heated by hot steam through a a steam jacket. Water is evaporated during the process and the end point temperature is often 120°C-140°C, but the fat is not severely degraded (Ockerman, 2000; Viswam, 2010). The agitator is also heated by steam, which helps to improve heat transfer in the mixture (Ockerman, 2000). Free-flowing fat is drained off. The whole process takes 1.5-3 hours (Viswam, 2010).

Table 2.2: Advantages and disadvantages of wet rendering system

Advantages	Disadvantages
<ul style="list-style-type: none"> ● Produces high-quality fat ● Less energy consuming 	<ul style="list-style-type: none"> ● High capital costs and maintenance costs

Continuous rendering systems can be wet or dry. The flow is continuous, thus the system is at atmospheric pressure. The retention time of continuous systems depends on the volume of the cooker, heat transfer efficiency, and the nature of the material. In continuous low-temperature systems, the moisture is removed by mechanical methods such as pressing or centrifugation (Ockerman, 2000). The material in the continuous low-temperature system is heated to a relatively low temperature, usually below 100°C for 10-30 minutes. After separation of the solid and liquid phase, solids are sent to drier and liquid is centrifuged. In semi-continuous system, material is heated in a batch cooker, but the subsequent processes such as pressing and centrifugation is carried out continuously (Anderson *et al.*, 2006). The comparison of batch and continuous dry rendering system is

shown in Table 2.3. The advantages and disadvantages of low-temperature rendering are in Table 2.4.

Table 2.3: Comparison of batch and continuous dry rendering system

	Advantages	Disadvantages
Batch dry rendering	<ul style="list-style-type: none"> ● Little material lost from the cooker. ● Cooking, pressurization, and sterilization can be operated in the same container (Ockerman, 2000). 	<ul style="list-style-type: none"> ● The quality of fat is poor. ● The meal produced is high fat-content. ● Labour intensive. ● To produce good quality fat, the raw material must be cut and washed. ● The cooking end-point is difficult to control.
Continuous dry rendering	<ul style="list-style-type: none"> ● Less footprint. ● Less labour intensive. ● Little material lost. ● Heat can be recovered 	<ul style="list-style-type: none"> ● Cannot sterilize in the cooker. ● This system has all the disadvantages of the batch system except labour intensive (Ockerman, 2000).

Table 2.4: Comparison of the low-temperature rendering system

Advantages	Disadvantages
<ul style="list-style-type: none"> ● Material need not be washed. ● Energy requirement is relatively low. ● Produce high-quality fat. ● Produce low-fat content meal. ● Little stickwater lost. 	<ul style="list-style-type: none"> ● High capital, repair, and maintenance costs. ● Highly trained operators required.

2.4 Pet Food

2.4.1 Pet Food History

Dogs were domesticated 16,000 years ago, and possibly were keeping company with humans for more than 30,000 years. After adopting them for protection, work, and companionship, people began to care about their nutritional needs (Guo Dong *et al.*, 2015; Kock & Gomelsky, 2015). The historical record of this changing approach dates back at least 2,000 years. In 37 BCE Virgil, an ancient Roman poet talked about the feeding of dogs in his *Bucolics*: Do not let the care of dogs be last (Virgil, 1826). Near the end of the 14th century, Gaston III, the eleventh Count of Foix Count in Southwestern France and an avid hunter, wrote a book in which he described how his beloved greyhounds were to be cared for (Walker Meikle, 2012). This included the reference to what they were fed: bran bread, some of the meat from the hunt, and if the dog was sick, goat's milk, bean broth, chopped meat or buttered eggs. The idea of preparing specialized food for cats came later than for dogs. This was likely due to cats being more independent and could feed themselves by hunting.

The commercial pet food industry started in 1860 with James Spratt's invention of the first dog biscuit in England (Gates, 2019). His biscuits were very popular and other companies soon began making their own versions (Gates, 2019). Canned dog food, "Ken-L Ration," was introduced in 1922 after World War I to make use of deceased horses. With the development of the internal combustion engine, horses were taken away from all sources of work (MacKay, 2018). So, horses were mainly disposed as canned pet food meat. The ongoing change to pet foods took place in the 1800s, from a largely canned/meat-based product to semi-moist and then to dry formulations (MacKay, 2018). It was in the 1900's that commercial pet food gained popularity (Gates, 2019). Then a big innovation in the pet food industry came out in the 1950s with the extrusion process to produce pellets (Gates, 2019).

Pet food changed over time from canned horse meat to products of higher quality, more balanced diet and more nutritious. The development of veterinary science promoted the development of health considerations of pet foods. These pet foods aim to provide more suitable diets for sick pets and help with their treatment for various ailments.

2.4.2 Nutrition of Pet Food

Pet food is a plant or animal material intended for consumption by pets, typically sold in the pet market or pet zone in a supermarket. Cat food and dog food are the most common products sold in the supermarket. Association of American Feed Control Officials (AAFCO) established standards for cat food and dog food. Nutrients required by dogs and cats are listed in the tables in Appendix 1 from the website of the US Food and Drug Administration established by AAFCO (Dzanis & D.V.M., 1997).

The dog is a member of the order carnivores, but nutritionally dog is a member of omnivores (MacDonald *et al.*, 1984). The cat, a true carnivore, requires a higher level of dietary protein for maintenance than a dog since their ability to synthesize amino acids is limited (Bauer, 1998). Compared to adult cats, kittens require more protein. Adult cats require about 10% to 14% of their dietary energy as protein while growing kittens require about 17% to 20% (Rogers & Morris, 1982; MacDonald *et al.*, 1984), while rats, dogs and humans only require 4% to 5% (Rogers & Morris, 1982). The dietary protein level provided to the cat has a minimal effect on the activity of hepatic enzymes in the liver, thus even in low protein condition, these enzymes handle the protein as in high levels of dietary protein condition (Rogers *et al.*, 1977; Rogers & Morris, 1982). Therefore cats require much protein.

The 10 essential amino acids listed in Appendix 1 include arginine, lysine, histidine, isoleucine, leucine, methionine, phenylalanine, threonine, tryptophan and valine (Rogers & Morris, 1979). It will pose a threat to the life of the cat if any of them is deficient in a cat's diet, especially when arginine is deficient. Morris and Rogers (1978) proved this by giving cats a single meal without arginine. Arginine deficiency causes the most severe response among responses of any other nutrient deficiency in cat diets. The feeding of a single meal of an arginine-free diet may result in hyperammonemia in less than one hour and cause severe hyperammonemia within two to five hours (MacDonald *et al.*, 1984). Symptoms include vocalization (moaning), emesis, ptyalism, hyperactivity, hyperesthesia, ataxia, tetanic spasms, emprosthotonus, extended limbs with exposed claws, apnea, and cyanosis (MacDonald *et al.*, 1984). One cat died 4.5 hours after taking only 8 grams of the diet in Morris and Rogers (1978) experiment. Since ornithine also prevents

hyperammonemia, it appears that the domestic cat cannot synthesize ornithine by themselves (Morris & Rogers, 1978). Arginine plays an indispensable role in dog diets as well as in cat diets. In dog diets, arginine has been found to promote the release of a number of metabolic hormones (National Research Council . Subcommittee on Dog, 1985).

Histidine is a structural component of proteins. It is essential in oxygen exchange and is a precursor of biologically active compounds such as histamine and carnosine (Butterwick *et al.*, 2015). The concentration of histidine is high in haemoglobin (Butterwick *et al.*, 2015). It plays a key role in oxygen exchange in the lung and other tissues (Cianciaruso, 1981). Puppies and kittens which are fed a histidine, leucine, isoleucine or valine deficient diet will experience weight loss, decreased serum albumin and haemoglobin concentrations and development of cataracts (Milner, 1979; Rogers, 1979; Quam *et al.*, 1987). If kittens cannot acquire enough isoleucine from the food, they will not only experience poor growth, but also porphyrin-like staining around the eyes, nose and mouth with ataxia and sloughing of paw pads (Hargrove *et al.*, 1984). Methionine, threonine and tryptophan are indispensable amino acids in the diet of the immature dog. Growth was significantly reduced and loss of weight started by being fed diets deficient in these amino acids in the research of Milner (1979). Synthesizing linoleic acid is a problem for dogs and cats, thus, a dietary source is essential for both of them (Watson, 1998). Linoleic acid is an omega-6 fatty acid that also helps maintain the health of the cats' skin (Watson, 1998).

Thirteen essential minerals are required by cat diets listed in Appendix 1. It is widely known that calcium and phosphorus are critical for the young including puppies and kittens. Plasma phosphorus and calcium are reported higher in the growth phase animals than those in the adult phase animals (Pineda *et al.*, 2013). Because of their close metabolic association, calcium and phosphorus are always considered together. Vitamin D is involved in the metabolism of calcium and phosphorus. The calcium: phosphorus ratio of 1.2:1 to 1.4:1 (by weight) in dog diets is generally considered optimal for maximum utilization, furthermore, this optimal ratio minimizes the vitamin D requirement (National Research Council . Subcommittee on Dog, 1985). Phosphorus and calcium are critical for maintaining strong bones and teeth throughout all life. However, excess calcium may be the

cause of stones in the urinary tract in cats. Struvite was the most common stone reported in cats until approximately 1993 when the incidence of calcium oxalate (CaOx) began to increase. 53% of stones contain CaOx and 47% contain struvite (Palm & Westropp, 2011). Although, dietary acidification can enhance the solubility of struvite crystals in the urine of cats, it also promotes the release of calcium carbonate from bone as a metabolic buffer, resulting in hypercalciuria (Kerl, 2014). This was proved by Tarttelin (1988) who fed cats with five different commercial cat food products and found that the urine sample with higher pH occurred to contain more struvite and less CaOx.

Potassium, chloride and sodium are the principal electrolytes of body fluid. They are crucial to maintain the osmotic pressure balance. The sodium in cats decreases (newborn 1.9 to 1.4 g/kg) when cats grow from kittens to adults but the potassium does not change significantly (2.3 g/kg) (Kienzle *et al.*, 1991). However, high sodium levels in cat food have been controversial for a long time (Nguyen *et al.*, 2017). High sodium levels are used to enhance water intake and urine volume to reduce the risk of urolithiasis, but taking too much sodium is harmful to cats, resulting in kidney failure and urolithiasis (Nguyen *et al.*, 2017). Chronic renal failure is always found in old cats. Cats suffering from this disease are recommended to have diets with antioxidants and lower levels of protein, phosphorus, sodium, higher levels of omega-3 fatty acids, B-vitamins than common diets. Signs of deficiency of potassium in dogs are poor growth, restlessness, muscular paralysis, a tendency to dehydration (Abbrecht & Vander, 1970), and lesions of the heart and kidney. Potassium affects the activity of plasma renin in all animals. The activity of plasma renin increases during depletion of potassium and decreases rapidly during repletion. The reactions appeared in the first depletion day in two of the dogs in Abbrecht and Vander (1970) experiment.

Vitamin E is a natural antioxidant and, together with selenium, is important for maintaining the stability of cell membranes (Watson, 1998). Zinc, a critical element, helps to regulate many aspects of cellular metabolism, also take part in the maintenance of a healthy coat and skin. Vitamin A also plays an important role to prevent skin disease and eye disease both for cats and dogs in addition to many other (Ihrke & Goldschmidt, 1983; Watson, 1998). Liver, cod liver oil, and retinyl acetate or palmitate are satisfactory sources of vitamin A. Iron and copper which

play similar roles as in human body are both essential for the prevention of anemia in cats and dogs. Iron is present in enzymes such as ferritin and hemosiderin in hemoglobin and myoglobin. Copper is required for normal iron metabolism but also has many other diverse functions. Vitamin K stimulates many metabolic activities, for example, vitamin K₁ (2-methyl-3-phytyl-1,4-naphthoquinone) stimulates prothrombin synthesis by the liver parenchymal cells in dogs (Anderson & Barnhart, 1964).

A special but important nutrient required by cats is taurine. Cats cannot synthesize taurine because they lack the enzyme to do so, and therefore, acquire taurine from their diets. A taurine deficiency in cats can lead to retinal degeneration and eventually blindness. Fish contains high levels of taurine. Providing cats with fresh fish regularly can help them prevent eye disease.

Different from cats, dogs are an omnivorous animal. Actually, both cats and dogs may thrive on vegetarian diets but dogs require less protein in their diets and are able to metabolize carbohydrates, and therefore, a vegan diet may be substantial if properly formulated and balanced (Knight & Leitsberger, 2016). It is well known that chocolate is toxic to dogs and can cause severe gastrointestinal bleeding and lesions of the brain and heart. Besides, onion and garlic, grapes and raisins, milk (some dogs and cats are lactose intolerant and suffer diarrhea; goats' milk is recommended), nutmeg, macadamia nuts, as well as various plants and other potentially ingested materials are also toxic for dogs.

2.4.3 Pet Food Industry

Companion animals play a more and more important role in human lives. In many households, companion animals are not only pets anymore, but also important family members. Keeping pets has many advantages. Families keeping pets have a better and healthier family relationship. With the companion of pets, the feeling of loneliness and isolation are always been reduced, especially for the elderly. Children who have pets tend to be more sociable, less selfish and more self-reliant, and develop a stronger immune system. With so many advantages, keeping pets is becoming more and more popular, and the exponential growth of pet food and pet care market has been witnessed in the past decade.

New Zealand has a large pet food market, as 64% of families own at least one companion animal. There are 4.6 million pets living with their families, the number is even larger than the population of people in New Zealand. Cats are the most popular pet in New Zealand with an average 1.8 cats per household. 28% of households own one or more dogs. The cat food market has a total volume of 31,353 tonnes per annum at a value of \$226.0 million and the dog food market has a total volume of 40,189 tonnes per annum at a value of \$168.0. New Zealand Pet Food Manufacturers Association is an industry association comprised of pet food manufacturers and companies that supply materials or services to the pet food manufacturing industry. This association was established in 1991 as a non-profit body. It has 74 members and 46 associate members which are suppliers of ingredients, equipment or services to the pet food industry.

Traditionally, pet foods have three categories: dry food/kibbles, wet food/canned food, raw. Among them, dry foods are the most common fed pet foods. Protein content in pet foods can range from 25 to 70% of the dry matter (Tran *et al.*, 2008). The food contains over 40% protein is a high-protein food.

Extrusion technology which is first well-known in the plastics industry has now been widely used in the pet food industry and referred to as extrusion-cooking. About 95% of dry pet foods are produced by this technology (Tran *et al.*, 2008). Food extruders (extrusion-cookers) is a member of the family of HTST (high-temperature short time)-equipment which is able to perform cooking tasks under high pressure (Mościcki & D.J., 2011). The extrusion process is the most important part of the whole process. This process begins with the dough. Raw materials and ingredients are mixed together and stirred thoroughly to form a dough-like consistency. This dough is then transferred into an expander, where the dough is cooked under pressurized steam or hot water. The quality of the product is controlled by the appropriate temperature, residence time, moisture and pH (Tran *et al.*, 2008). This process is under high pressure and temperature condition. The dough is then extruded through the die and cut into pellets by a knife. This process is done under high pressure. Once the dough pieces are released from the high temperature and high pressure, they puff up. The resulting kibble is then dried to remove moisture, followed by coating, where kibbles are sprayed with oil and vitamins. After coating, it comes to the end of the process: weighing and bagging.

Worldwide, the most commonly used extrusion equipment is single-screw extruders. More than 80% of all dry pet foods are produced on single-screw extruders (Moscicki, 2011).

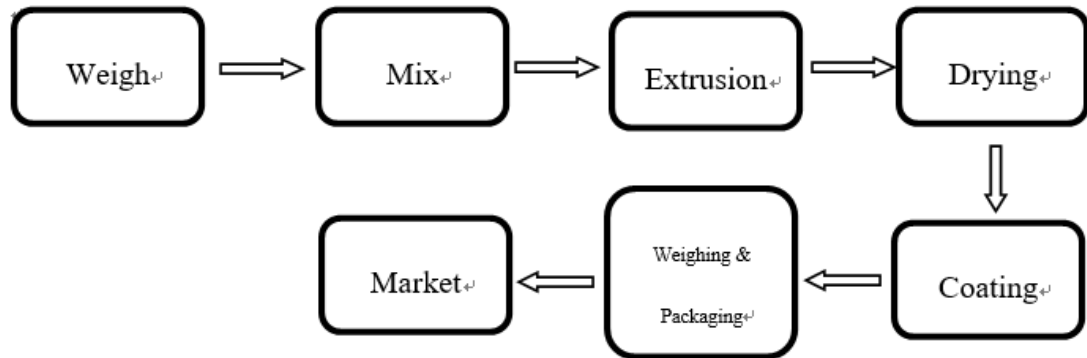


Figure 2.1: A production line of dry pet food

Nearly half of pet owners totally believe or somewhat believe that dry food is healthier than wet food, especially good for pet oral health, as the hard kibbles help pets clean their teeth. Extrusion process develops the palatability and digestibility of dry foods because the process makes proteins more susceptible to digestive enzymes. But as a process involved high pressure and temperature, loss of nutrients in dry pet foods cannot be avoided. The degradation and oxidation of proteins, enzymes, fat and vitamins is affected by many factors. Lipid oxidation is always a challenge in pet food shelf life. The extrusion process accelerates their oxidation. Some vitamins are fragile under physical or chemical treatment. The losses of vitamins C, B, A, D and E amount to 15–20% (Moscicki, 2011).

Wet pet food processing is less complicated than dry pet food processing. First, ingredients are mixed thoroughly in a mixer. Then the ingredients are boiled or steamed. Once the mixture is well cooked, it is transferred to empty and clean containers, and the containers are sealed. This step is followed by sterilization by heating the sealed cans under a specific temperature for a required time to kill hazardous microorganisms.

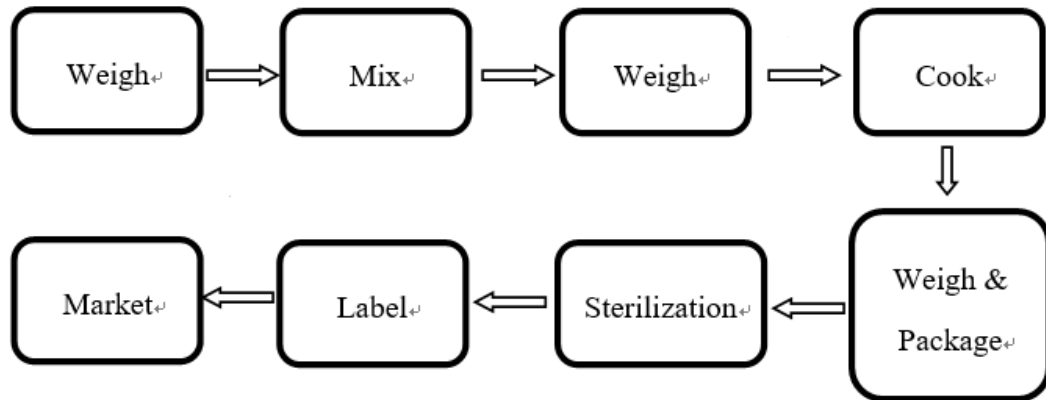


Figure 2.2: A production line of wet pet food

In recent years, new technology has been used in the food industry as well as the pet food industry: freeze-drying technology. Freeze-drying, also called lyophilization or cryodesiccation, is a low-temperature drying process in which the solvent or the suspension medium is crystallized at low temperature and sublimed from the solid phase directly to vapour phase after that (Haseley, 2018). The advantages and disadvantages of freeze-drying are listed in Table 2.5 below (Haseley, 2018). The freeze-drying of pet foods is more expensive but healthier (Figure 2.3).

Table 2.5: Advantages and disadvantages of freeze-drying.

Advantages	Disadvantages
<ul style="list-style-type: none"> ● Heat-sensitive components are well protected during the processing/Fewer nutrients loss. ● The liquid product can be accurately dosed ● Final products contain a low level of moisture ● The original shape can be maintained. 	<ul style="list-style-type: none"> ● High investment, maintenance, operating costs. ● Require skillful and trained workers.



Figure 2.3: Freeze-drying quail cat food

2.4.4 Concluding Statement

Koi carp is an excellent protein and lipids food resource. Carp is rich in minerals especially phosphorus, potassium, sodium, calcium and magnesium. In 170 g carp, the composition of these minerals is 903, 726, 107, 88 and 65 mg respectively. These minerals are important in the growth of pets. Carp also provides iron, zinc, copper, manganese and selenium.

The ten essential amino acids (arginine, lysine, histidine, isoleucine, leucine, methionine, phenylalanine, threonine, tryptophan and valine) required by cats and dogs can all be found in koi carp. Leucine, lysine, valine, arginine and alanine are plentiful in carp. In addition, carp is rich in aspartic acid and glutamic acid. For a cat, carp can provide a rare but extremely important nutrient: taurine.

Carp is rich in vitamin A which helps cats and dogs maintain healthy skin and eyes. However, carp cannot provide enough vitamin E, vitamin D and vitamin K for pets, requiring other ingredients added to carp to provide the nutrients.

In general, koi carp is a promising potential pet food raw material, providing enough nutrients with low cost. At the same time, New Zealand waterways can be protected by harvesting koi carp and using it to make pet food.

3 MATERIALS AND METHODS

A series of trials were done to investigate the yield of oil under different rendering conditions with the same rendering method. The water content and ash content were analyzed. The main product of the rendering process, fish meal, was used to make two kinds of pet food: wet pet food and dry pet food. Further trials and surveys were done to find out the palatability of the pet food and public acceptance.

3.1 Materials

3.1.1 Fish

The koi carp used in this study were obtained from the lower Waikato River by Rangiriri (Figure 3.1) near the Lake Waikare. The koi carp were bow hunted by the staff of the Department of Biological Sciences from the University of Waikato, and stored in a chilli-bin before being transported to campus. At university, the fish were stored at -15°C. Before use, the fish were thawed at room temperature, which took 12 hours during the winter, and the weight of the fish was noted. The fish were scaled using fish scaler bought in market, filleted manually and the fillets were minced using blender. The minced samples were bagged in sample bags and frozen or refrigerated before use.

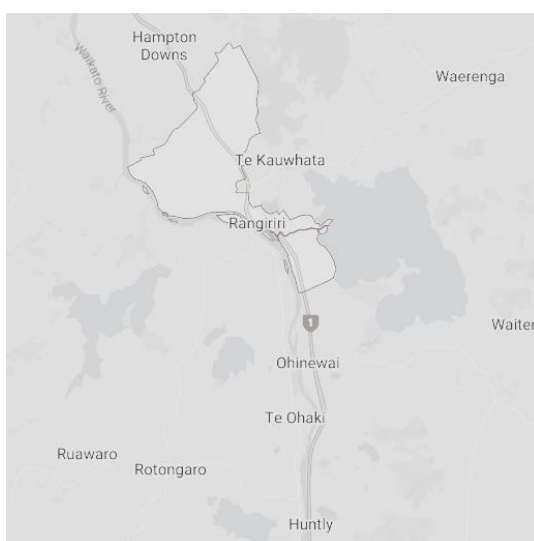


Figure 3.1: Location of Rangiriri

3.1.2 Chemicals

n-Hexane (99% Merck KGaA, Darmstadt, Germany) was used for Soxhlet extraction of oil from dried samples.

3.1.3 Other Materials and Equipment

In the rendering process, the apparatus used were hot plate/autoclave (Autoclave SX – 700E, TOMY KOGYO CO..LTD), centrifuge (Sigma Laboratory Centrifuges 6-15) and oven. The desiccator was used to keep the dried sample or the ash sample after the ash test.

Raw chicken mince from the supermarket was used for manufacturing the pet food. A standard kitchen oven was used for baking the dry pet food, while a kitchen steamer was used for the wet pet food.

For Soxhlet extraction, extraction apparatus (flask, distillation tube, thimbles, glass wool, boiling chips, heater, funnel, cylinder, extraction tube) was used, and an oven under an extraction hood for evaporating the solvent.

Moisture contents were carried out using a Contherm oven.

Ash contents were carried using Muffle furnace (FHX-14).

3.2 Methods

3.2.1 Rendering Methods

Before rendering, the fish was scaled, the inedible offal was removed, and the fish was filleted. The fillet was chopped into pieces and minced. The minced fish was used for rendering, solids content, ash content and fat content.

Wet rendering

50-100g of minced fish was transferred into a beaker with different weights of water added. The mixture was heated on a hot plate and stirred continuously for different periods of time (10-80 minutes). After heat treatment, the cooked mixture was weighed, and centrifuged at 4000 rpm for 10 min. The stickwater was separated and weighed before being transferred to the oven. The solid phase was weighed and dried in the oven. The temperature of the oven was 60°C.

Autoclave rendering

100 g of minced fish was added into a beaker with 100 g of water. The fish and water were stirred before covering the beaker with aluminum foil. Several holes were punctured in the foil. The beaker was weighed and then autoclaved. The temperatures used for autoclaving were 90, 105, 110, 120, 130 and 135°C. The treatment time was 20 min after reaching the set temperature. The autoclave took about one hour to cool down. After heat treatment, the beaker was weighed, then the cooked mixture was centrifuged at 4000 rpm for 10 min. The stickwater and solid phase were separated and weighed before being transferred to the oven.

3.2.2 Analytical Methods

Water content

A known weight of sample (Wet weight) was placed on a pre-weighed foil dish. The sample was dried in the oven at 60°C overnight. The sample was weighed again the next day after being totally dried and the weight of the foil dish subtracted to give the dry weight. The water content was calculated by:

$$\text{Water content \%} = \left(\frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \right) \times 100$$

Solid content

$$\text{Solid content \%} = 100 - \text{Water content}$$

Ash content

The weight of the porcelain dish was measured first (Weight₀). A known weight of dry same (Weight₁) was placed into a porcelain crucible. The sample was heated up to 500°C for two hours. After cooling, the weight of the dish and the ash in it was measured (Weight₂). The weight of the ash and ash content was calculated as:

$$\text{Ash weight} = \text{Weight}_2 - \text{Weight}_0$$

$$\text{Ash content \%} = \frac{\text{Ash weight}}{\text{Weight}_1} \times 100$$

Fat content

The fat in the sample was extracted overnight by Soxhlet extraction using hexane. A known mass of sample was placed in a cellulose Soxhlet extraction thimble, this was topped up with glass wool and the total mass measured. This was placed in

the Soxhlet extractor. 130 ml of hexane was added to a round bottomed flask, some boiling chips added to the flask and placed on the heating element. The soxhlet extractor was placed on top and a condenser connected to a cooling water supply placed above the Soxhlet extractor. The heating element was set to 69°C, and the Soxhlet extraction was carried out overnight, checking periodically that no hexane was being lost. After extraction, the thimble was allowed to drain, and then the solvent evaporated from the thimble by placing the thimbles in an oven that was vented to an extraction hood. The total mass of the defatted sample, wool and thimble was measured and the defatted sample mass was obtained. Fat content was calculated by:

$$\text{Fat content \%} = \left(\frac{\text{Initial weight} - \text{Defatted weight}}{\text{Initial weight}} \right) \times 100$$



Figure 3.2: Soxhlet extraction apparatus

3.2.3 Pet Food Making

Dry pet food (Nibbles)

Dry pet food was made of koi carp meal and minced chicken breast meat. Two types of nibbles with different ingredients proportions were cooked. The weight ratios of koi carp meal to chicken were 1:1 and 1:2. The mixture of koi carp and minced chicken breast meat was kneaded thoroughly. The mixture was placed in a plastic sample bag with a corner cut off. The mixture was squeezed out into a long row

and cut into 1 cm sized nibbles. These nibbles were roasted in an oven under 150°C for 20 min.

Wet pet food

The wet pet food was made of rendered fish and minced chicken breast meat. The wet pet food also had two types containing different proportions of fish to chicken (1:1 and 1:2). The meat paste was stirred completely before transferred to a 12 cm diameter plate. The paste was steamed for 30 min in a steamer (24 cm diameter) after the water was boiling.

3.2.4 Acceptance Survey and Taste Testing

Ethics approval was obtained from the Faculty ethics committee for the pet food customer survey and taste testing.

The customer survey was carried out in Hamilton by giving questionnaires to 60 participants. The participants were given a handout introducing this project. The handout and the questionnaire are included in Appendix 2 and 3.

The taste testing was conducted in two groups of 15 cats from different families, indoors at the cat's home. For the dry pet food, each cat was introduced to five nibbles. For the wet pet food, each cat was introduced to three pieces of wet pet food. Each cat was observed with the pet food for five minutes after which the food was removed and the amount of food remaining was counted. Cat behaviour was noted.

4 RESULTS AND DISCUSSION

The meat in Koi carp, like other fish, is plentiful and contains good quality protein which is the core of making use of koi carp. In addition, possible by-products like collagen and oil provide other choices to make comprehensive use of the koi carp. To make use of fish, rendering is a useful method to handle the fish, with fish meal being one of the main products during the process. However, the stickwater is valuable as well. To reduce waste and maximize the value of the fish, making stickwater powder or collagen recovery may be possible method.

The trials included wet rendering and autoclave rendering, to investigate how different conditions influence the oil content in the stickwater, providing information about oil recovery for the possible koi carp disposal factory in the future.

The weight of the captured fish ranged from 1.2 kg to 3 kg. Most koi carp were a red colour (Figure 4.1) or orange with some black spots (Figure 4.2). The koi carp that contained roe had a round soft stomach (Figure 4.2).



Figure 4.1: Red koi carp



Figure 4.2: Koi carp with roe

4.1 Trials

4.1.1 Proximate analysis of wet rendering

Two batches of minced fish was prepared. The first batch was used in Group 1-2 (Group 1 is 10 min group and Group 2 is 20 min group) and the second batch was used in Group 3-5 (40, 60 and 80 min respectively) in wet rendering. Before rendering, several samples were taken from each batch of raw minced fish. Raw fish was dried and the water content, fat content and ash content was determined (Tables 4.1 – 4.8). On average the water content was 77% and solids content was 23% for batch 1 and 74% and 26% for batch 2. The water content was 3% - 6% higher than the data analysed by Viswam (2010). Ash content was 7.4% of the dry solids for batch 1 and 6.2% for batch 2. Fat content was 13.7% of the dry solids for batch 1 and 20.5% for batch 2. At a wet basis, the meal content was similar at 19.7 to 19.9%, ash content was slightly higher for the first batch at 1.69% which was nearly half of the 3% obtained by Viswam (2010) and fat content was higher for the second batch at 5.13%. The second batch of minced fish contained a female fish with fish roe, hence the greater fat content.

Table 4.1: Water content of the first batch of raw fish used in wet rendering

Sample	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
1	14.0259	3.2206	10.8053	77.04	22.96
2	15.3689	3.5092	11.8597	77.17	22.83
3	9.2298	2.0869	7.1429	77.39	22.61

Table 4.2: Ash content of the first batch of raw fish used in wet rendering

Sample	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	2.113	0.1495	7.08	92.92
2	2.5063	0.1929	7.70	92.30

Table 4.3: Fat content of the first batch of raw fish used in wet rendering

Sample	Dry weight (g)	Dry weight after extraction (g)	Fat content (g)	Fat content (%)
1	3.2018	2.7206	0.4812	15.03
2	3.4435	3.015	0.4285	12.44

Table 4.4: Water content of the second batch of raw fish used in wet rendering

Sample	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
1	14.0893	3.631	10.4583	74.23	25.77
2	11.5075	2.8978	8.6097	74.82	25.18
3	8.3256	2.0401	6.2855	75.50	24.50
4	9.462	2.3291	7.1329	75.38	24.62

Table 4.5: Ash content of the second batch of raw fish used in wet rendering

Sample	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	2.867	0.1837	6.41	93.59
2	2.3249	0.1379	5.93	94.07

Table 4.6: Fat content of the second batch of raw fish used in wet rendering

Sample	Dry weight (g)	Dry weight after extraction (g)	Fat content (g)	Fat content (%)
1	3.9736	3.1699	0.8037	20.23
2	3.2256	2.5556	0.67	20.77

Table 4.7: Composition of raw fish used in wet rendering

Raw fish	Water content (%)	Solid content (%)	Volatile dry content (%)	Ash content dry basis (%)	Fat content dry basis (%)
Batch 1	77.13	22.87	92.61	7.39	13.74
Batch 2	74.98	25.02	93.83	6.17	20.50

Table 4.8: Composition of raw fish used in wet rendering on a wet basis

Raw fish	Fat content (% wet basis)	Meal content (% wet basis)	Ash content (% wet basis)
Batch 1	3.14	19.73	1.69
Batch 2	5.13	19.89	1.54

4.1.2 Wet Rendering

To decide the weight of water required for rendering, preliminary trials were done. Before the main trials, the temperature of the minced koi carp during the heating process was recorded first (Table 4.9). The hot plate was set to the highest heating range. After 21 minutes, the temperature was close to 100 degrees and the mixture was boiling.

Table 4.9: Temperature of the minced koi carp in in wet rendering

Time (min)	1	3	5	7	9	11	13	15	17	19	21	23
Temperature (°C)	26	30	42	54	60	68	73	79	88	93	95	95

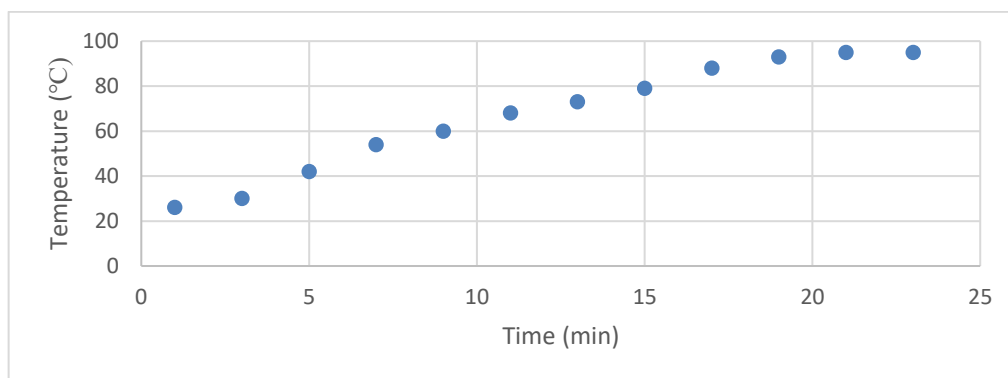


Figure 4.3: Temperature of the minced koi carp in in wet rendering

Different heat treatment times of 10, 20, 40, 60 and 80 minutes were used (Recorded as Groups 1-5, 1 being 10 minutes and 5 being 80 minutes). The temperature of group 1 and 2 reached 65 and 93°C respectively, while Groups 3, 4 and 5 reached temperatures of 95, 96 and 96°C respectively. During the whole process, the mixture was stirred manually by spatula for better heat transfer and avoid loss of product due to splashing. Therefore, much water was evaporated in long-time heat treatment (3.79, 12.32, 28.89, 32.88 and 46.54% of the water content was evaporated in group 1 to 5 respectively). To prevent the fish being scorched, in 60 and 80 min groups, the weight ratio of raw minced fish to water was set at 1:1.5 and 1:2 respectively. In Group 1, 2 and 3 heating time groups, the same weight of water was added (Table 4.10).

Table 4.10: The ratio of koi carp to water

Rendering time (min)	10	20	40	60	80
Koi carp(g):Water(g)	1:1	1:1	1:1	1:1.5	1:2
Mass of raw koi carp used (g)	50.1	50.6	101.98	100.28	101.7
Mass of water used (g)	51.1	5.03	101.7	154.5	200.4

During heating, the water changed from a light red colour to a clear colour, with the minced fish changing to a white colour after 10 min (Figure 4.4). The final cooked

minced fish meal was yellow and granular. During this stage, there was a strong unpleasant odour of fish.



Figure 4.4: Minced fish and water mixture before and after heat treatment

After heating, the beaker was removed from the hot plate and cooled down before weighing. The next step was centrifugation where the mixture was centrifuged at 4000 rpm for 10 min. The centrifuged mixture showed three layers, the bottom layer was the solid cooked meal, on the top was a thin layer of fat where yellow oil droplets could be seen, sometimes with a floating white fat-like substance, while the middle layer was clear light-yellow liquid, the stickwater (Figure 4.5).



Figure 4.5: Centrifuged rendered fish in tube

The solid and liquid layers were separated and weighed. The water/solid content, volatile dry/ash content (dry basis), fat content (dry basis) and the reduction in fat were calculated. The summary results of rendered fish and stickwater are in Table 4.19. For each group, mass balance was calculated to see how much water, solids and fat come in and out of the rendering process. The details of each group after rendering are shown in Tables 4.11 to 4.15 and a mass balance is shown from Figures 4.8 to 4.12. Solids contents of the meal ranged between 22.8 to 28% while stickwater solids content was low at 1.6% for Group 1 and increased with rendering time 3.6%.

Table 4.11: Water content of stickwater and solids after rendering in wet rendering group 1 (10min)

Whole mass after rendering (g)		97.8			
Mass of stickwater (g)		62.1			
Mass of solids (g)		33.46			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	62.1	1.0	61.1	98.40	1.60
Solids	8.2297	1.8797	6.3500	77.16	22.84
	7.0773	1.960	5.1173	72.31	27.69
	9.4138	2.5086	6.9052	73.35	26.65
	7.7017	1.8198	5.8819	76.37	23.63

Table 4.12: Water content of stickwater and solids after rendering in wet rendering group 2 (20min)

Whole mass after rendering (g)		89.4			
Mass of stickwater (g)		53.1			
Mass of solids (g)		32.46			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	53.1	1.1	52	97.93	2.07
Solids	7.7896	2.0590	5.7306	73.57	26.43
	7.2320	1.8567	5.3753	74.33	25.67
	7.6422	2.1650	5.4772	71.67	28.33
	7.8850	1.7792	6.1058	77.44	22.56

Table 4.13: Water content of stickwater and solids after rendering in wet rendering group 3 (40min)

Whole mass after rendering (g)		148.4			
Mass of stickwater (g)		60.3			
Mass of solids (g)		80.80			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	60.3	2.4	57.9	96.02	3.98
Solids	8.4024	2.0585	6.3439	75.50	24.50
	8.4966	2.0781	6.4185	75.54	24.46
	9.8063	2.3372	7.4691	76.17	23.83
	10.3766	2.5101	7.8665	75.81	24.19

Table 4.14: Water content of stickwater and solids after rendering in wet rendering group 4 (60min)

Whole mass after rendering (g)		200.3			
Mass of stickwater (g)		99.2			
Mass of solids (g)		98.45			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	99.2	3.1	96.1	96.88	3.12
Solids	8.2671	1.872	6.3951	77.36	22.64
	7.562	1.7181	5.8439	77.28	22.72
	9.1637	2.0311	7.1326	77.84	22.16
	6.7137	1.5937	5.12	76.26	23.74

Table 4.15: Water content of stickwater and solids after rendering in wet rendering group 5 (80min)

Whole mass after rendering (g)		172.3			
Mass of stickwater (g)		88.3			
Mass of solids (g)		80.80			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	88.3	3.2	85.1	96.38	3.62
Solids	6.5466	1.5754	4.9712	75.94	24.06
	8.5061	2.0203	6.4858	76.25	23.75
	10.1921	2.3488	7.8433	76.95	23.05
	9.4056	2.2441	7.1615	76.14	23.86

The stickwater changed from liquid into jelly-like solid soon after being placed in the fridge. The stickwater has 3.62% solids, not all of which will be gelatine. In comparison, to make 500 ml of jelly, 14.2 g of gelatine is needed, which equates to 2.76% solids. After being dried in the oven, the stickwater became orange and crispy and stuck on the tin foil (Figure 4.6). It was not easy to peel off but had a pleasing salty and fishy smell.



Figure 4.6: Dried stickwater



Figure 4.7: Ash of samples

The ash content of rendered fish and stickwater are given below in Tables 4.16 and 4.17. Generally the longer the rendering time, the greater the ash content in the fish meal, which makes sense as there was a greater solubilisation of solids from the meal into the stickwater with increasing rendering time (the stickwater had a greater percentage solids with increasing rendering time). The ash content in the stickwater also increased with increasing rendering time, probably due to salts present in the minced fish leaching out into the stickwater.

Table 4.16: Ash content of the fish meal from wet rendering

Group	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	1.8963	0.114	6.01	93.99
	2.2635	0.1207	5.33	94.67
2	1.6563	0.0835	5.04	94.96
	2.0431	0.0895	4.38	95.62
3	1.7754	0.1514	8.53	91.47
	2.4784	0.1948	7.86	92.14
4	2.0336	0.1008	4.96	95.04
	1.9188	0.0826	4.30	95.70
5	2.5572	0.223	8.72	91.28
	2.3654	0.2134	9.02	90.98

Table 4.17: Ash content of stickwater from wet rendering

Group	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	0.3848	0.0473	12.29	87.71
	0.2557	0.0423	16.54	83.46
2	0.2353	0.0457	19.42	80.58
	0.2613	0.04547	17.40	82.6
3	0.209	0.0552	26.41	73.59
	0.229	0.0576	25.15	74.85
4	0.7988	0.1445	18.09	81.91
	1.1469	0.2093	18.25	81.75
5	0.423	0.166	39.24	60.76
	0.5609	0.1981	35.32	64.68

Fat content of the meal ranged between 14.4% to 18.4%. Groups 1 and 2 used fish that had a fat content of 14% on a dry basis while Groups 3-5 used fish that had a fat content of 20% on a dry basis. For Groups 3-5 there was a general reduction in fat with increasing rendering time, while for Groups 1 and 2, fat content of the resulting meal was higher than the raw fish suggesting the temperature obtained for 10 minutes (65°C) and 20 minutes (reached 93°C at around 20 minutes) was not high enough to solubilise the fat, but high enough to solubilise some of the protein/salt fraction to increase the fat content in the final meal. The similar wet rendering process (wet rendering 45 min) was done by Viswam (2010) and got the oil yield 1.4% of the original minced koi carp. In Group 3 (wet rendering 40 min), the fat reduction was 15.95% dry basis which was 1.5% of the original minced fish. It is nearly the same with Viswam (2010) result.

Table 4.18: Fat content of fish meal from wet rendering

Group	Dry weight before extraction (g)	Dry weight after extraction (g)	Fat content (g)	Fat content (%)
1	2.8086	2.4044	0.4042	14.39
	3.7749	3.1992	0.5757	15.25
2	2.3803	1.9898	0.3905	16.41
	2.5194	2.1165	0.4029	15.99
3	2.0453	1.6700	0.3753	18.35
	1.9401	1.6013	0.3387	17.46
4	2.0564	1.7186	0.3378	16.43
	0.3164	1.858	0.3398	15.46
5	2.2236	1.8533	0.3703	16.65
	2.6285	2.2447	0.3838	14.60

Mass Balance of Wet Rendering Group 1 (10 min)

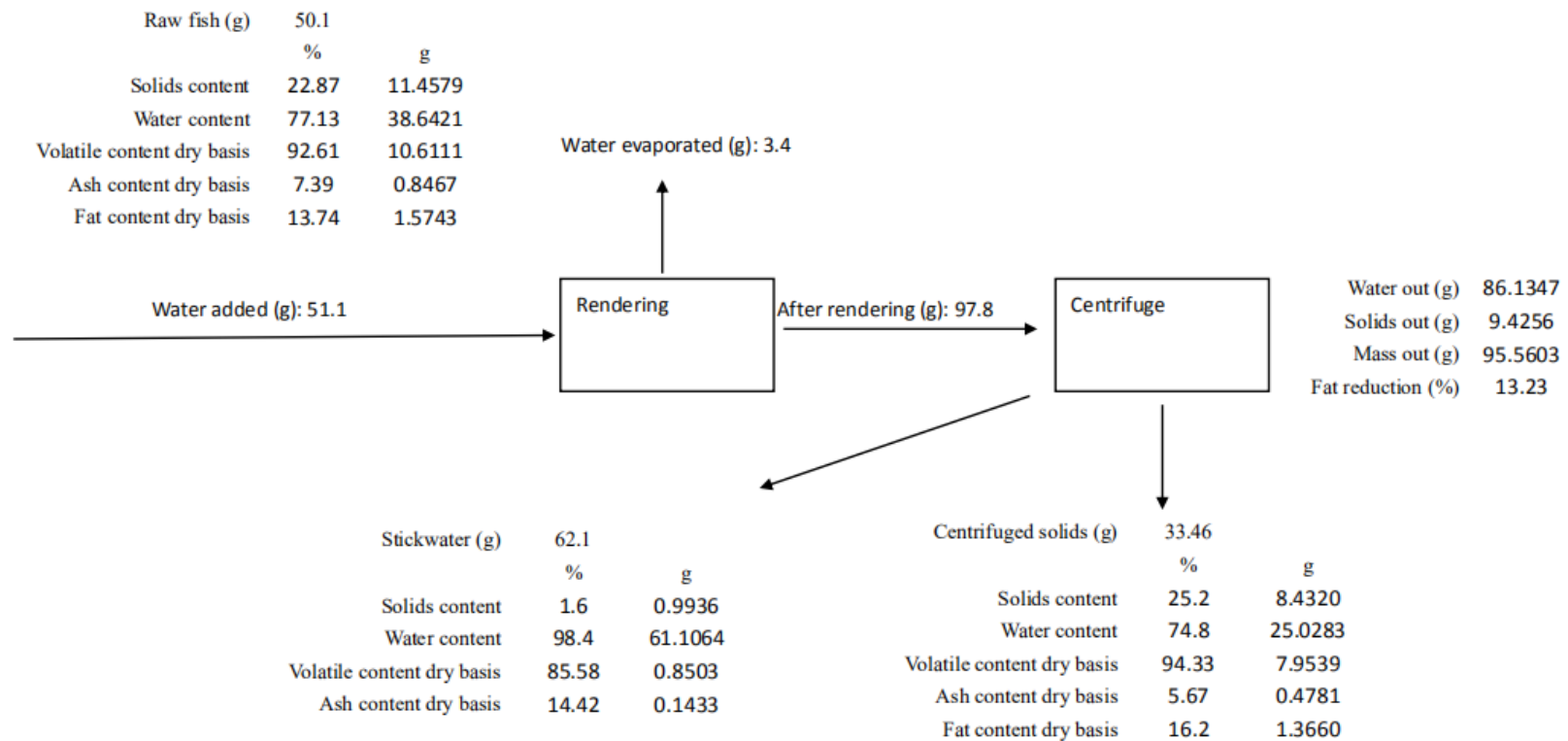


Figure 4.8: Mass balance of wet rendering group 1 (10 min)

Mass Balance of Wet Rendering Group 2 (20 min)

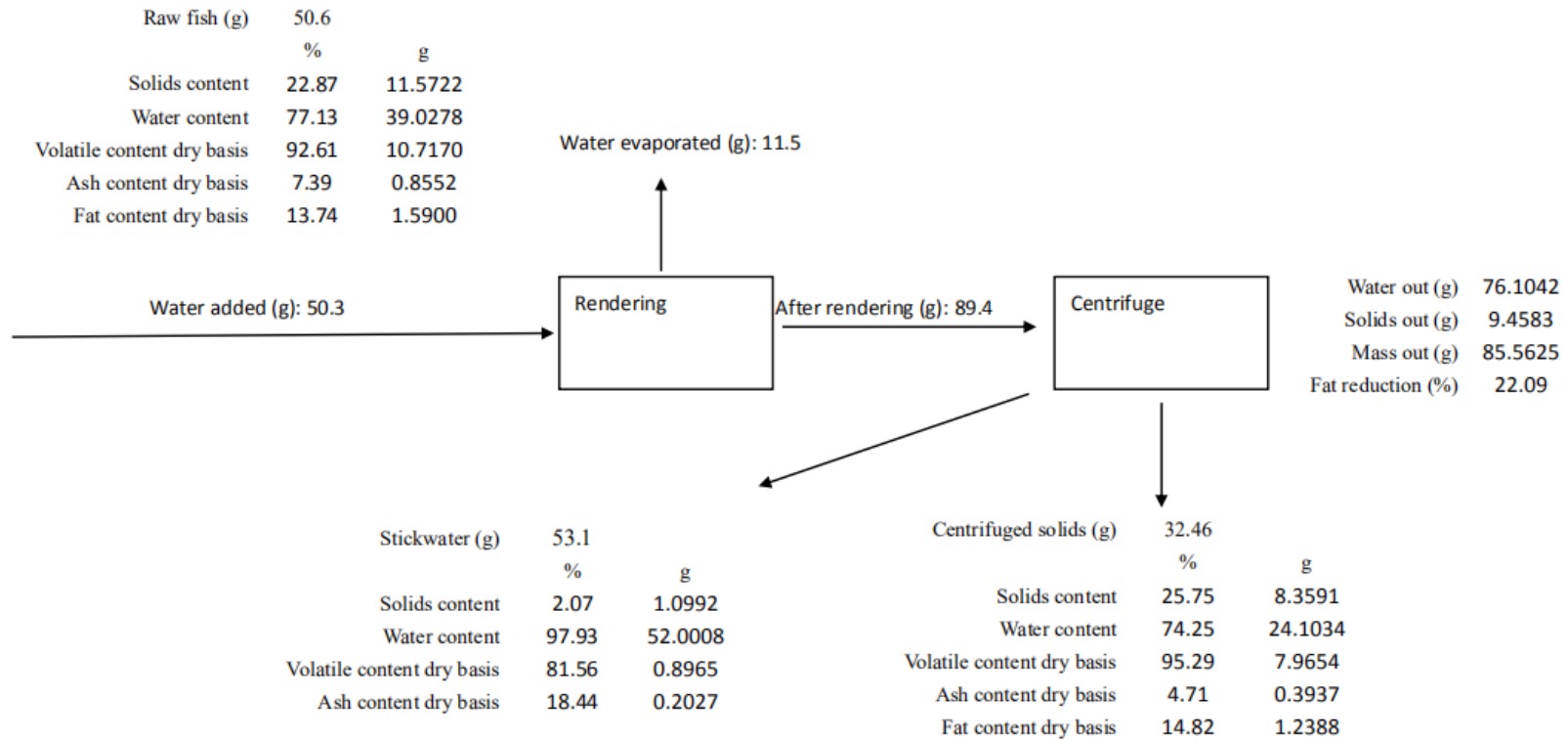


Figure 4.9: Mass balance of wet rendering group 2 (20 min)

Mass Balance of Wet Rendering Group 3 (40 min)

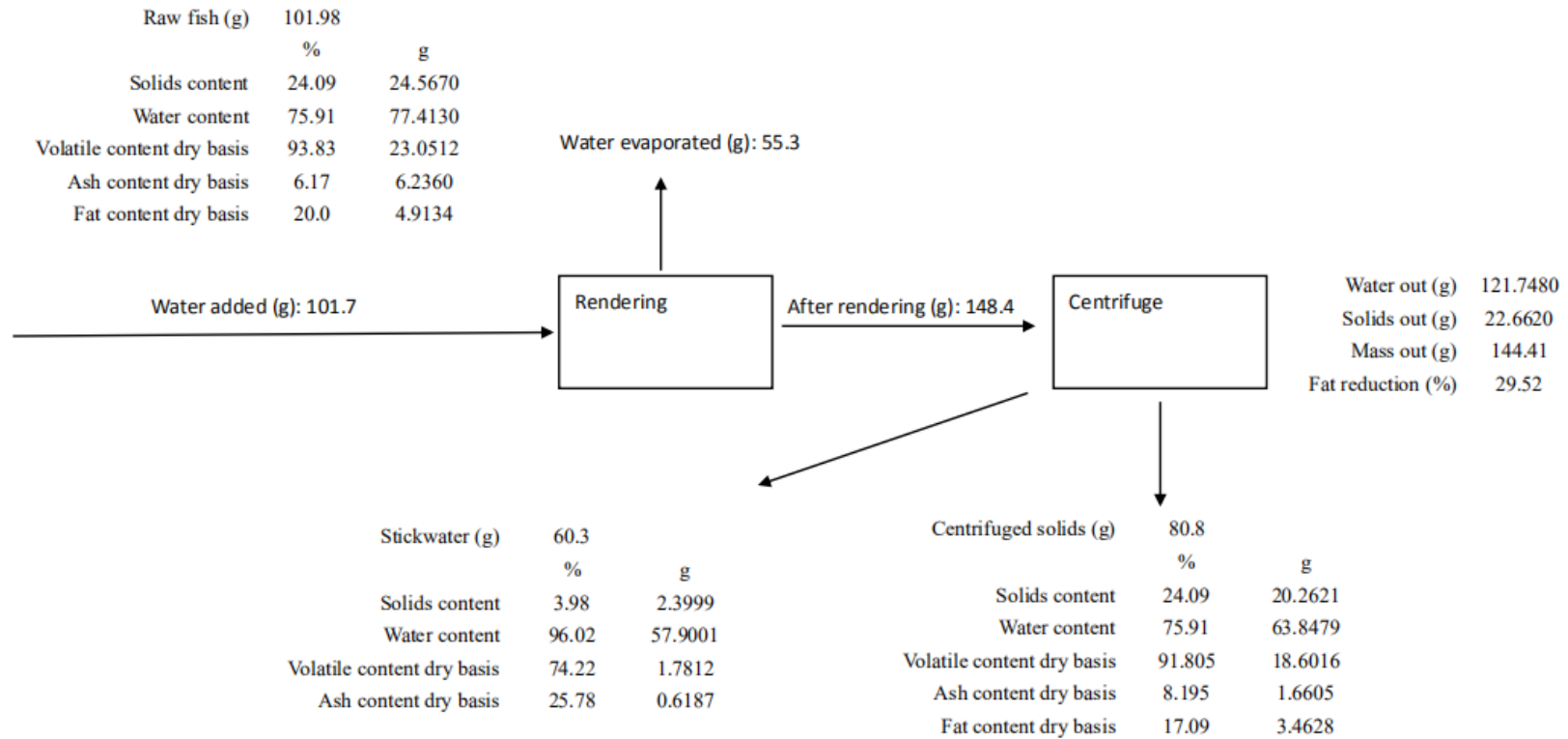


Figure 4.10: Mass balance of wet rendering group 3 (40 min)

Mass Balance of Wet Rendering Group 4 (60 min)

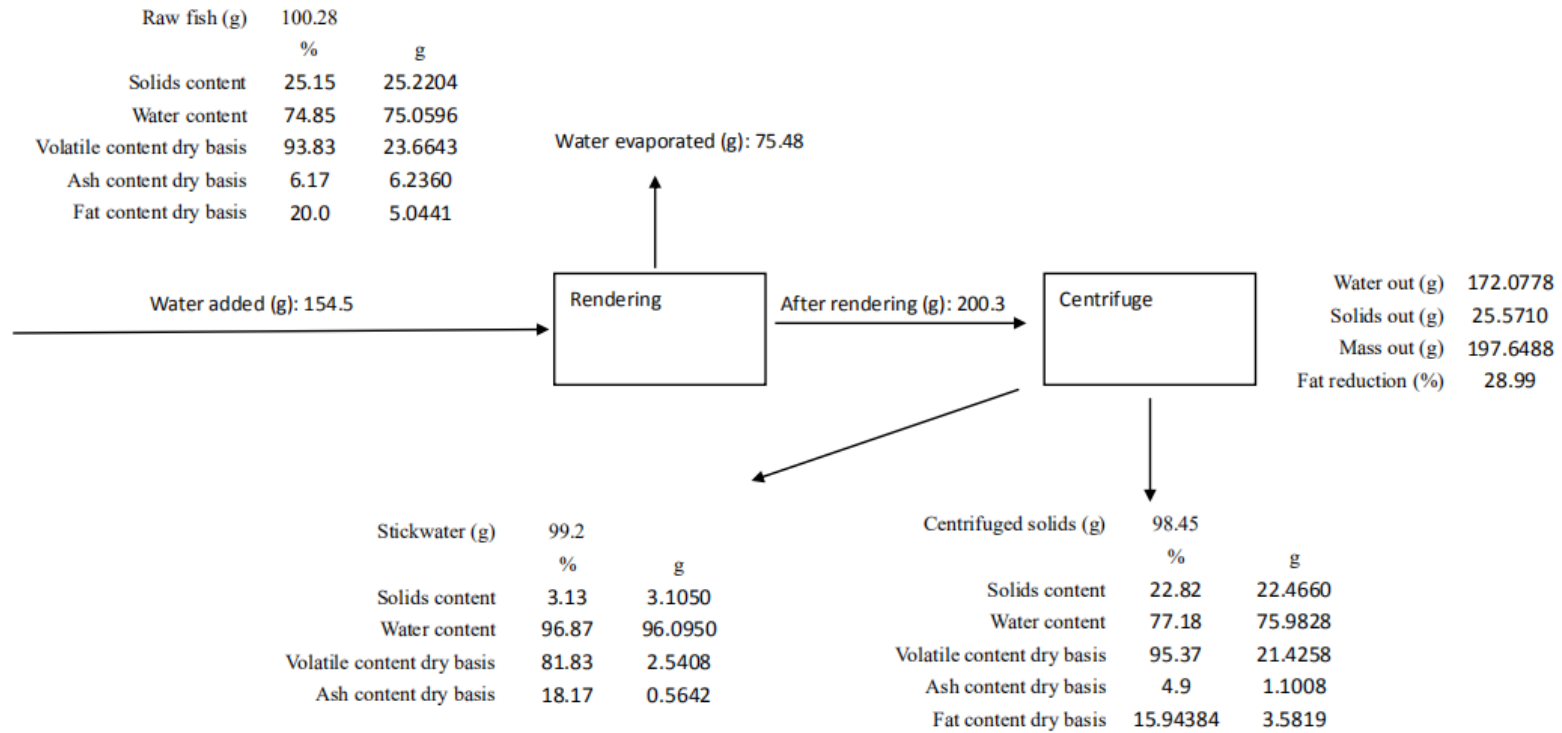


Figure 4.11: Mass balance of wet rendering group 4 (60 min)

Mass Balance of Wet Rendering Group 5 (80 min)

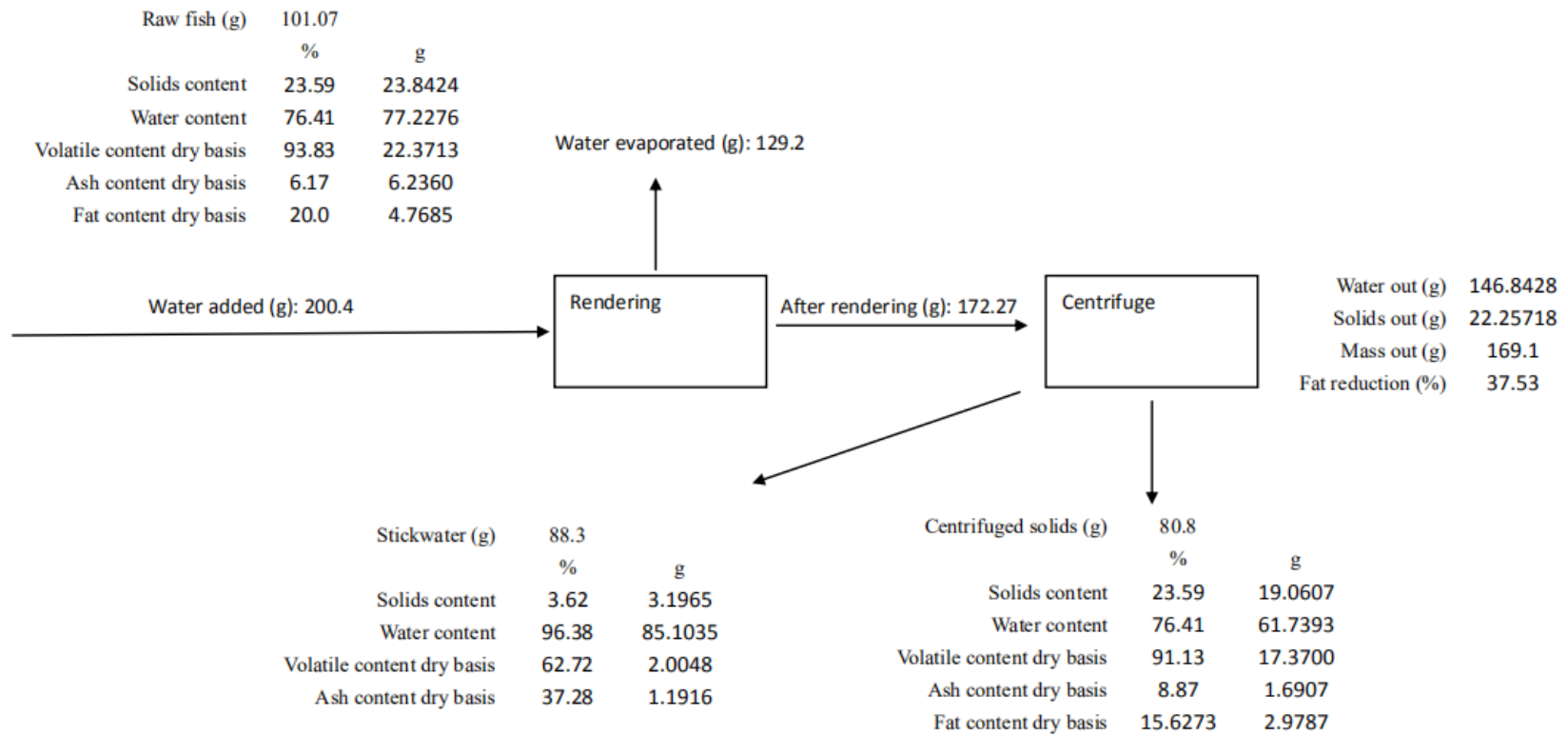


Figure 4.12: Mass balance of wet rendering group 5 (80 min)

Table 4.19: Summary results of fish and stickwater of wet rendering

Group	Water content (%)		Solid content (%)		Volatile dry content (%)		Ash content dry basis (%)		Fat content dry basis (%)	Reduction in fat (%)
	Fish	Stickwater	Fish	Stickwater	Fish	Stickwater	Fish	Stickwater	Fish	Fish
1	74.80	98.40	25.20	1.60	94.33	85.58	5.67	14.42	15.31	13.23
2	74.25	97.93	25.75	2.07	95.29	81.56	4.71	18.44	14.82	25.09
3	75.91	96.02	24.09	3.98	91.81	74.22	5.19	25.78	17.09	29.52
4	77.60	96.87	22.40	3.13	95.37	81.83	4.63	18.17	15.94	29.68
5	76.41	96.38	23.59	3.62	91.13	62.72	4.87	37.28	15.63	37.53

From the data, the water content of the raw fish mince was found to be high, around 75% of the fish was water. Ash is the inorganic matter that is unable to be incinerated. The average ash content was 5.014%. The reduction in fat represented the amount of the fish oil that was separated from the rendering process which means the potential fish oil yield of each rendering condition. The line chart below helps to make the comparison more straightforward.

Heat and stirring were the main factors that rupture the fat cell during rendering. In all groups, mixing was done through the whole heating process. Except for Group 1, the other four groups were done under boiling temperature. Fish mince was rendered for 10 min and the temperature reached 65 °C in Group 1.

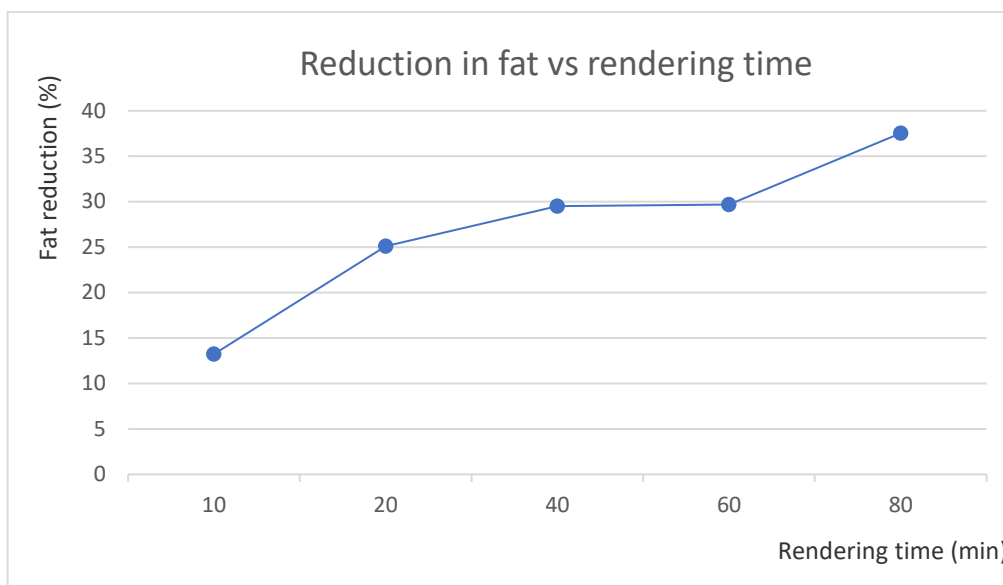


Figure 4.13: Reduction in fat of wet rendering

Fat reduction was found to be the lowest in Group 1 and the highest in Group 5. 13.23% and 37.53% respectively. From the line chart, the reduction in fat grows slowly in the first 40 min from 13.23% to 29.52%. It maintains in Group 3 and 4 in which fish was rendered for 40 and 60 min respectively. It was possible because the fat cells which were easy to break had been ruptured and the oil was released during that stage, but the time was not enough for more fat to be released. The data raises to almost 40% after rendering 80 min which is three times the result of rendering only 10 min in Group 1.

To get a high oil recovery, enhancing the rendering time is a method. However, long rendering time means large energy consuming. Thus, rendering 20 to 40 min seems to be an appropriate rendering option.

4.1.3 Proximate analysis of autoclave rendering

Before the autoclave rendering, the raw koi carp was dried and water content, fat content and ash content were analysed shown in Table 4.20 – 4.24. The raw fish used had a high fat content of 30.34% dry basis and 8.46% wet basis due to the fish roe. This fat content was approved by the study of Viswam (2010). The water content of the raw fish was 72.12% and the ash content was 7.29%. On wet basis, this batch of fish had 2.03% ash content and 19.42% meal content.

Table 4.20: Water content of the raw fish used in autoclave rendering

Sample	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
1	11.922	3.5523	8.3697	70.20	29.80
2	10.2337	2.6076	7.6261	74.52	25.48
3	10.6306	2.8846	7.746	72.87	27.13
4	11.1001	3.233	7.8671	70.87	29.13

Table 4.21: Ash content of the raw fish used in autoclave rendering

Sample	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	2.4187	0.1785	7.38	92.62
2	2.6227	0.189	7.21	92.79

Table 4.22: Fat content of the raw fish used in autoclave rendering

Sample	Dry weight (g)	Dry weight after extraction (g)	Fat content (g)	Fat content (%)
1	3.1095	2.1446	0.9649	31.03
2	2.8773	2.024	0.8533	29.66

Table 4.23: Composition of raw fish used in autoclave rendering

	Water content (%)	Solid content (%)	Volatile dry content (%)	Ash content dry basis (%)	Fat content dry basis (%)
Raw fish	72.12	27.88	92.71	7.29	30.34

Table 4.24: Composition of raw fish used in autoclave rendering on a wet basis

Fat content (% wet basis)	Meal content (% wet basis)	Ash content (% wet basis)
8.46	19.42	2.03

The water evaporated in autoclave was little, same weight of water was added in each group. The following table shows the mass of raw fish and water used.

Table 4.25: Mass of raw fish and water used in autoclave rendering

Group	1	2	3	4	5	6
Mass of raw fish used (g)	87.2	99.6	99.3	99.3	89.6	99.6
Mass of water added (g)	87.9	101.1	101.0	100.5	90.7	100.3

4.1.4 Autoclave Rendering

For autoclave rendering, raw fish was cooked for 20 minutes at 90, 100, 110, 120, 130 and 135°C (labelled as Group 1-6 respectively). The raw fish used for autoclave rendering had a high fat content of 30.34% on a dry basis due to the presence of fish roe. The water content of raw fish was 72.12% and the ash content was 7.29% on a dry basis.

The amount of water evaporated was small (1.16, 1.82, 2.24, 4.04, 5.1 and 5.32% for groups 1-6 respectively). After rendering, the mass and water content of rendered meal and stickwater in each group was analysed (Table 4.26 to 4.31). The mass balance is shown in Figure 4.14 to 4.19. The water content of rendered meal did not vary much and ranged between 69% to 74%, but was slightly lower than that obtained for wet rendering. The highest stickwater solids content was 3.79% in Group 5 while the lowest was 2.44% in Group 1 which was the only group rendered under 100°C. Overall, the solids content in the stickwater from autoclave rendering was similar to wet rendering. The summary results are shown in Table 4.35.

Table 4.26: Water content of stickwater and solids after rendering in autoclave rendering group 1 (90°C)

Whole mass after rendering (g)		173.3			
Mass of stickwater (g)		97.2			
Mass of solids (g)		75.01			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	97.2	2.4	94.8	97.56	2.44
Solids	8.1454	2.1267	6.0187	73.89	26.11
	9.3512	2.3818	6.9694	74.53	25.47
	11.9387	3.2927	8.646	72.42	27.58
	10.2979	3.155	7.1429	69.36	30.64

Table 4.27: Water content of stickwater and solids after rendering in autoclave rendering group 2 (100°C)

Whole mass after rendering (g)		199.3			
Mass of stickwater (g)		114.9			
Mass of solids (g)		83.91			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	97.2	3.7	111.2	96.78	3.22
Solids	9.1694	2.3809	6.7885	74.03	25.97
	9.2784	2.488	6.7904	73.19	26.81
	7.4472	2.0542	5.393	72.42	27.58
	8.1041	2.2351	5.869	72.42	27.58

Table 4.28: Water content of stickwater and solids after rendering in autoclave rendering group 3 (110°C)

Whole mass after rendering (g)		196.5			
Mass of stickwater (g)		116.9			
Mass of solids (g)		73.56			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	116.9	4	112.9	96.58	3.42
Solids	7.1847	2.1184	5.0663	70.52	29.48
	8.0718	2.631	5.4408	67.41	32.59
	7.6114	2.3707	5.2407	68.85	31.15
	8.0122	2.4647	5.5475	69.24	30.76

Table 4.29: Water content of stickwater and solids after rendering in autoclave rendering group 4 (120°C)

Whole mass after rendering (g)		192.8			
Mass of stickwater (g)		107.6			
Mass of solids (g)		81.69			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	107.6	3.4	104.2	96.84	3.16
Solids	9.9975	2.6862	7.3113	73.13	26.87
	6.9021	1.8832	5.0189	72.72	27.28
	8.6457	2.2797	6.366	73.63	26.37
	10.5843	2.9286	7.6557	72.33	27.67

Table 4.30: Water content of stickwater and solids after rendering in autoclave rendering group 5 (130°C)

Whole mass after rendering (g)		172.2			
Mass of stickwater (g)		102.9			
Mass of solids (g)		67.41			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	102.9	3.9	99	96.21	3.79
Solids	7.6893	2.2827	5.4066	70.31	29.69
	6.1806	1.8679	4.3127	69.78	30.22
	6.9038	1.9891	4.9147	71.19	28.81
	6.5699	2.0278	4.5421	69.13	30.87

Table 4.31: Water content of stickwater and solids after rendering in autoclave rendering group 5 (135°C)

Whole mass after rendering (g)		190.7			
Mass of stickwater (g)		100.7			
Mass of solids (g)		87.83			
	Wet weight (g)	Dry weight (g)	Water content (g)	Water content (%)	Solid content (%)
Stickwater	100.7	3.3	97.4	96.72	3.28
Solids	7.1912	1.8129	5.3783	74.79	25.21
	10.2643	2.6638	7.6005	74.05	25.95
	7.7713	1.8591	5.9122	76.08	23.92
	9.8712	2.5843	7.2869	73.82	26.18

The ash content of rendered fish and stickwater are given in Table 4.32. In each group, two samples were tested. Rendered meal ash content ranged from 2.16% to 5.74%. The data is higher than what Viswam (2010) reported in his trials (2.2%) where the fish was rendered under 120°C. The ash content in the autoclaved meal was lower than that obtained for wet rendering, but generally higher in the stickwater. High temperature should have promoted increased solubilisation of material into the stickwater resulting in a higher ash content in the meal, but this was not observed. It may be because the rendering was done without stirring, therefore the soluble composition was not fully released in the stickwater.

Table 4.32: Ash content of rendered fish in autoclave rendering

Group	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	2.1328	0.0688	3.23	96.77
	2.3777	0.0558	2.35	97.65
2	2.509	0.119	4.74	95.26
	2.4055	0.1312	5.45	94.55
3	2.1118	0.0456	2.16	97.84
	2.3678	0.0818	3.45	96.55
4	2.6919	0.0818	3.04	96.96
	1.8872	0.063	3.34	96.66
5	2.2824	0.0552	2.42	97.58
	2.0231	0.0576	2.85	97.15
6	1.8773	0.0891	4.75	95.25
	1.787	0.0917	5.13	94.87

Table 4.33: Ash content of stickwater in autoclave rendering

Group	Dry weight (g)	Ash content (g)	Ash content (%)	Volatile dry content (%)
1	0.1956	0.0428	21.88	78.12
	0.3414	0.0717	21.00	79.00
2	1.1045	0.1678	15.19	84.81
	2.3807	0.4504	18.92	81.08
3	0.8458	0.2537	30.00	70.00
	1.4254	0.4649	32.62	67.38
4	0.5245	0.0912	17.39	82.61
	0.5334	0.1035	19.40	80.60
5	1.0804	0.2633	24.37	75.63
	0.948	0.2285	24.10	75.90
6	1.6198	0.3298	20.36	79.64
	0.5442	0.129846	23.86	76.14

Data of fat content dry basis after rendering is given below. The dry basis fat content in each group ranged from 29.46% (Group 5) to 32.25% (Group 1). All of the groups used the raw fish material with 30.34% fat content dry basis, which is probably the reason why the meal had a higher fat content compared to meal obtained from wet rendering. The fat reduction was found to be the lowest in Group 1 (11.81%) and the highest in Group 5 (20.00%), 1.00% to 1.7% of the original raw fish respectively, indicating higher rendering temperature leads to more fat reduction in meal. This result coincided with the 1.5% oil yields obtained by Viswam (2010). From Group 1 to Group 4, the fat reduction increased with the temperature, after which it declined in Group 5 (130°C) and Group 6 (135°C), which suggests 120°C is the optimal temperature for fat reduction.

Table 4.34: Fat content of rendered fish in autoclave rendering

Group	Dry weight before extraction (g)	Dry weight after extraction (g)	Fat content (g)	Fat content (%)
1	3.1597	2.182	0.9777	30.94
	3.2979	2.2343	1.0636	32.25
2	2.0348	1.4018	0.633	31.11
	2.2371	1.5219	0.7152	31.97
3	2.4408	1.6832	0.7576	31.04
	2.6037	1.8293	0.7744	29.74
4	2.2688	1.5957	0.6731	29.67
	2.8989	1.9803	0.9186	31.69
5	1.9843	1.3778	0.6065	30.56
	1.8669	1.3169	0.55	29.46
6	2.5659	1.7578	0.8081	31.49
	2.6285	1.8285	0.8	30.44

Mass Balance of Autoclave Rendering Group 1 (90°C)

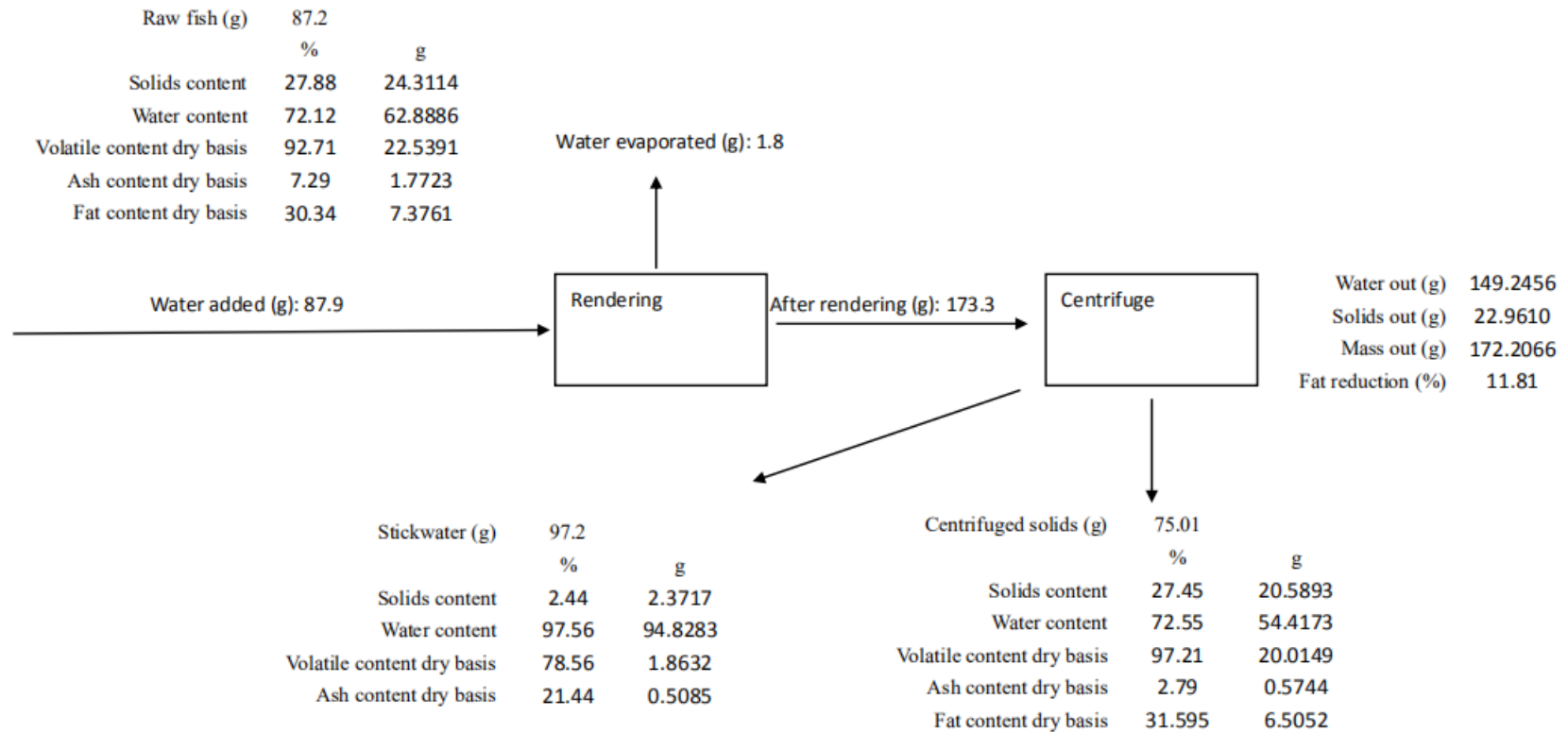


Figure 4.14: Mass balance of autoclave rendering group 1 (90°C)

Mass Balance of Autoclave Rendering Group 2 (100°C)

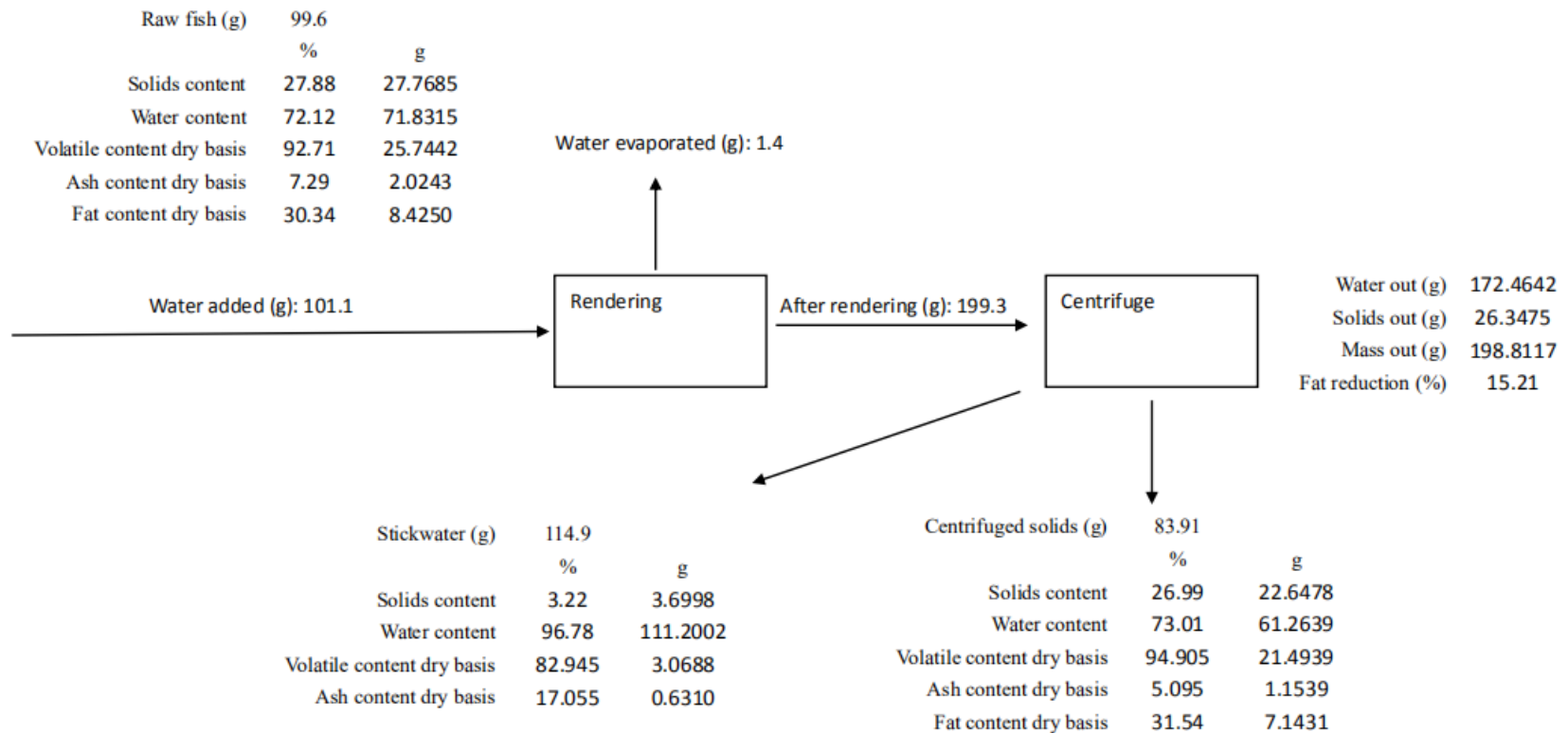


Figure 4.15: Mass balance of autoclave rendering group 2 (100°C)

Mass Balance of Autoclave Rendering Group 3 (110°C)

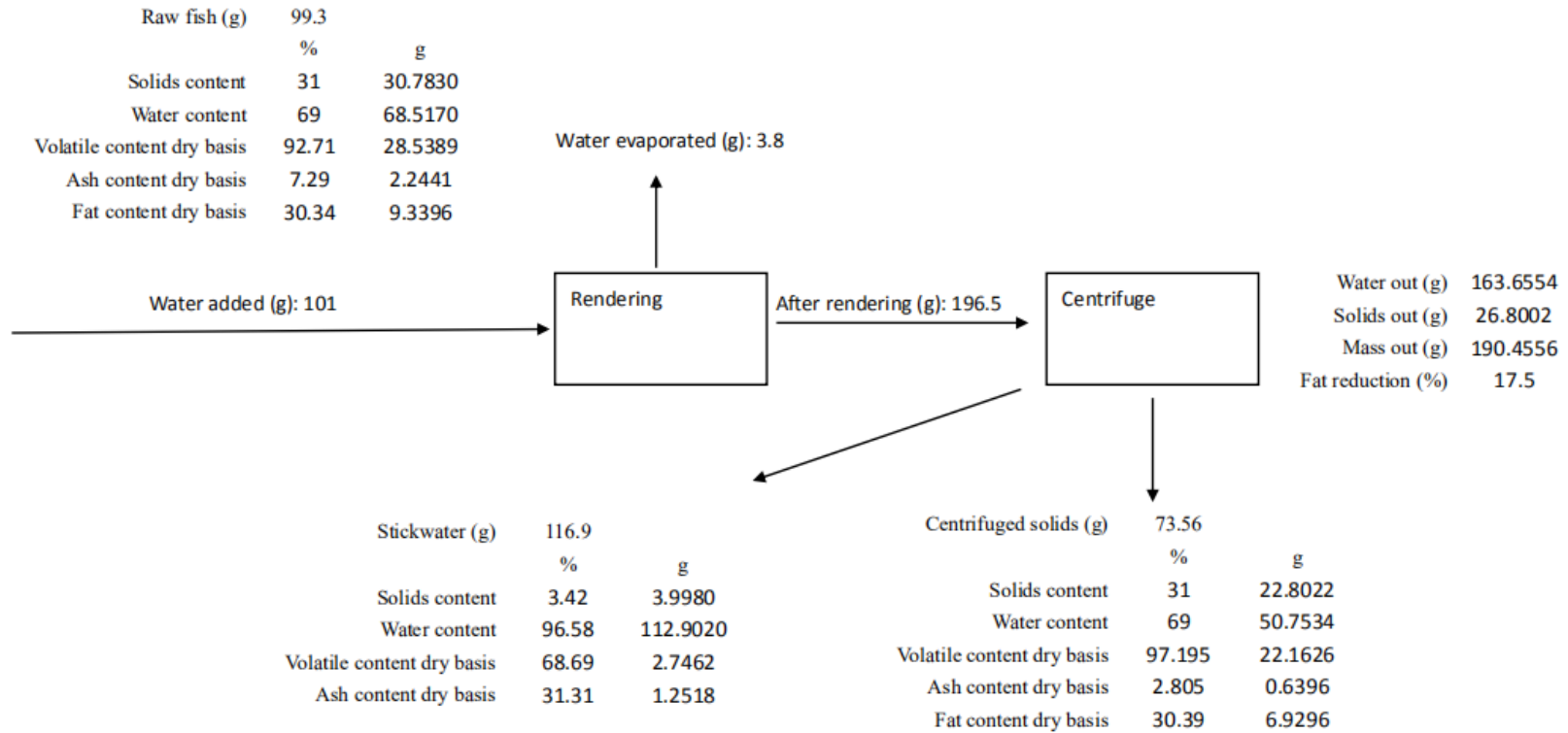


Figure 4.16: Mass balance of autoclave rendering group 3 (110°C)

Mass Balance of Autoclave Rendering Group 4 (120°C)

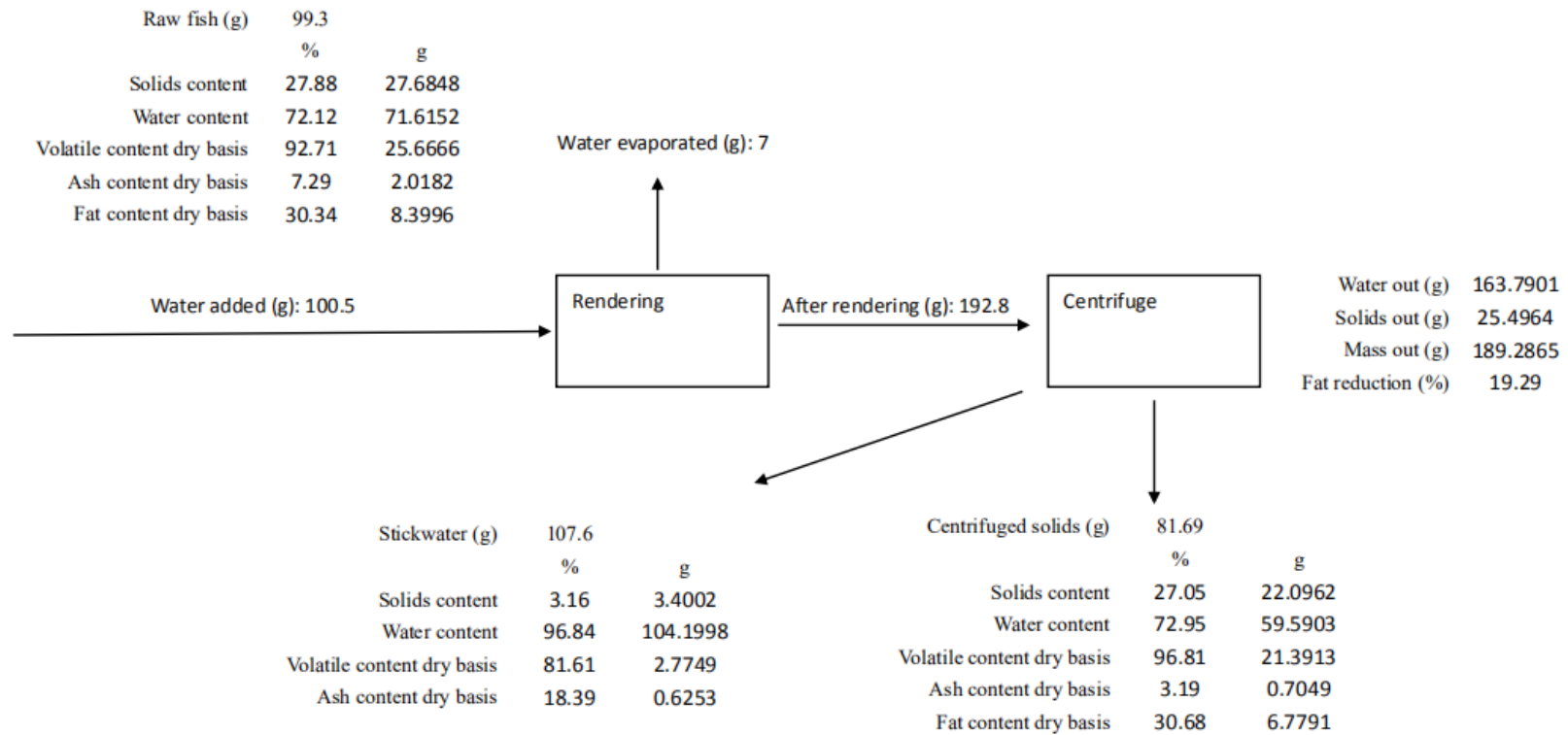


Figure 4.17: Mass balance of autoclave rendering group 4 (120°C)

Mass Balance of Autoclave Rendering Group 5 (130°C)

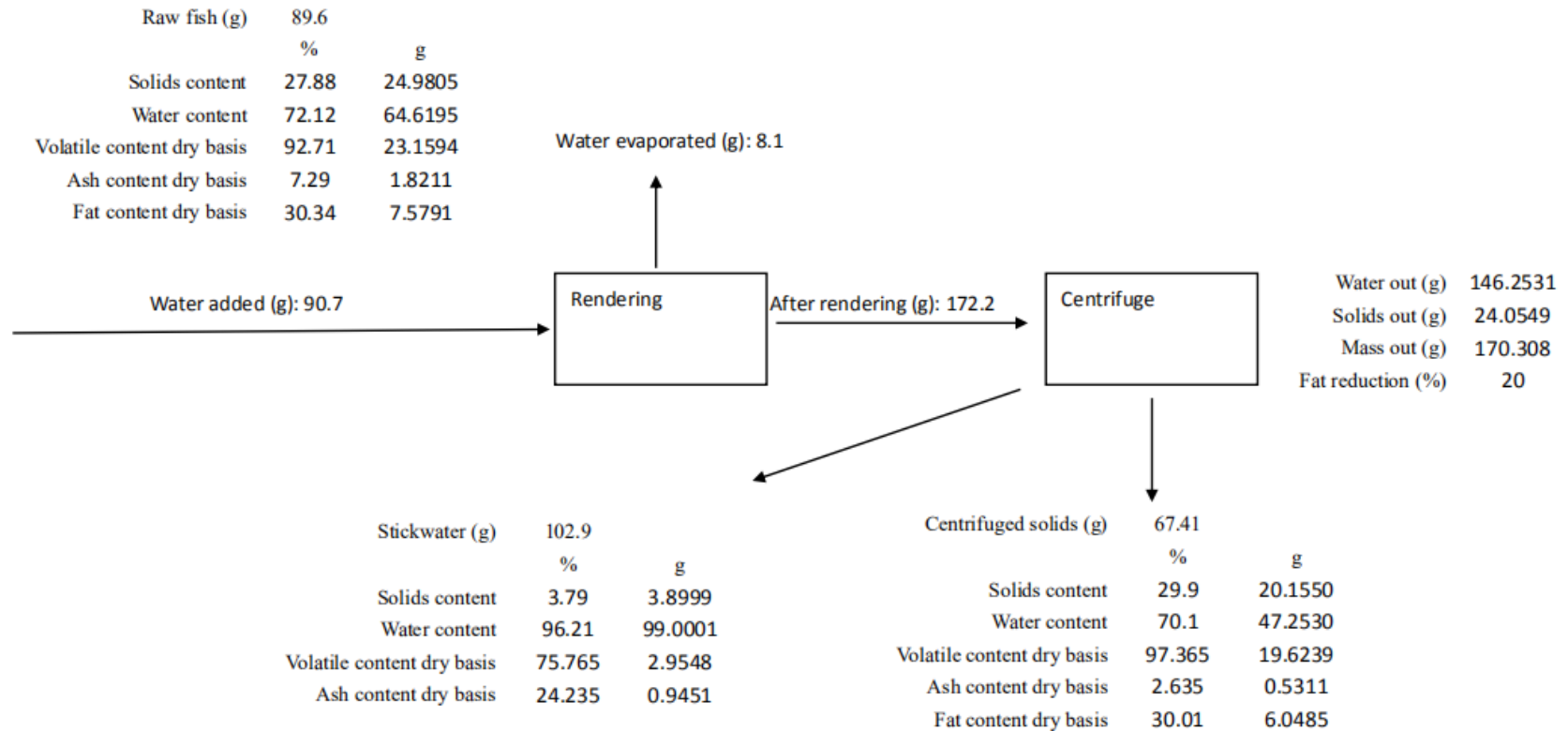


Figure 4.18: Mass balance of autoclave rendering group 5 (130°C)

Mass Balance of Autoclave Rendering Group 6 (135°C)

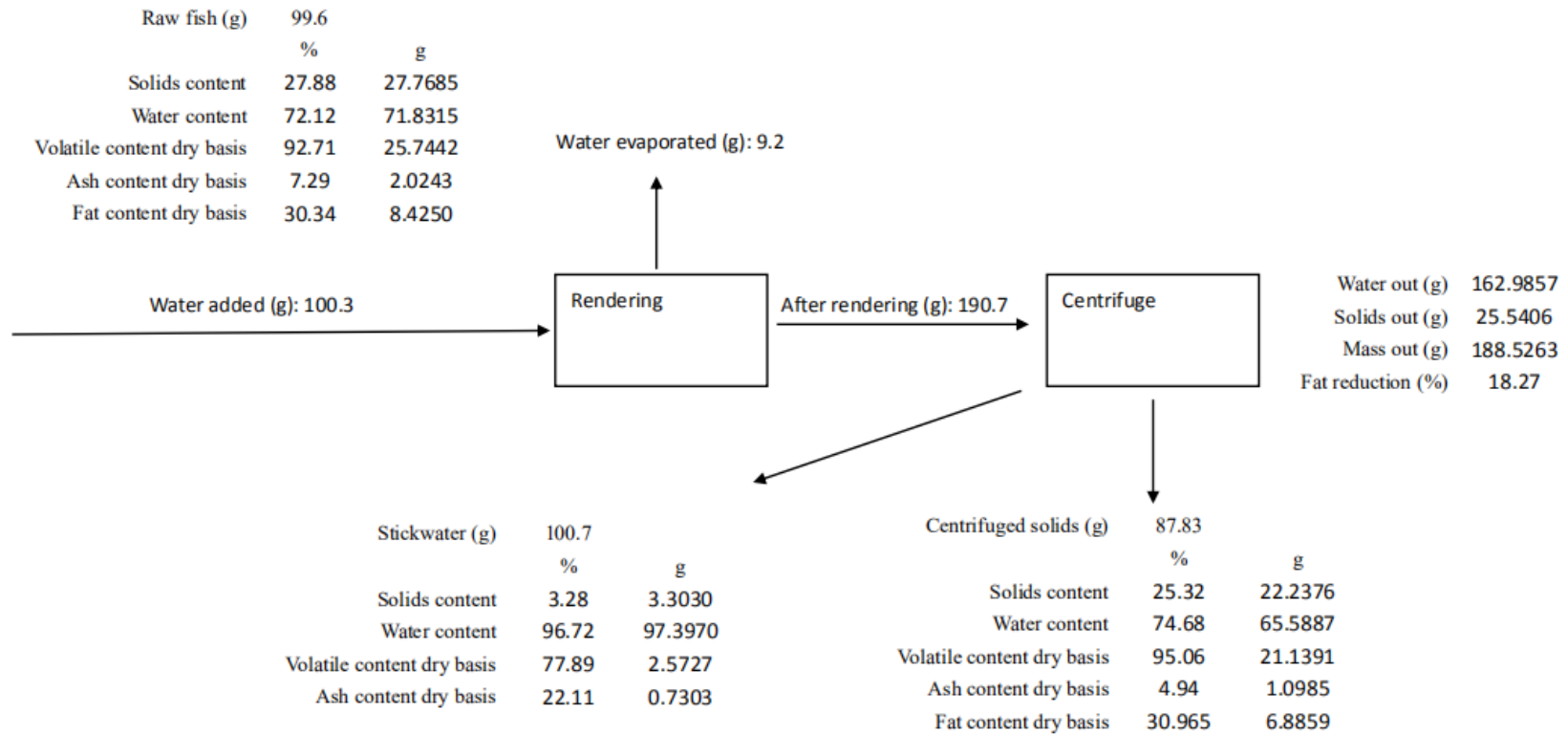


Figure 4.19: Mass balance of autoclave rendering group 6 (135°C)

Table 4.35 shows the summary of data of rendered fish and stickwater from autoclave rendering. The fat reduction increased with the rendering temperature from 11.81% to 19.39% in Group 1-4. In Group 4-6, the data remained in the range of 19.39% to 20.00%. The lowest water content of solids appeared in Group 3, only 69%, while the highest was 74.68% in Group 6.

Table 4.35: Summary results of fish meal and stickwater of autoclave rendering

Group	Water content (%)		Solid content (%)		Volatile dry content (%)		Ash content dry basis (%)		Fat content dry basis (%)	Reduction in fat (%)
	Fish	Stickwater	Fish	Stickwater	Fish	Stickwater	Fish	Stickwater	Fish	Fish
1	72.55	97.56	27.45	2.44	97.21	78.56	2.79	21.44	31.60	11.81
2	73.01	96.78	26.99	3.22	94.91	82.95	5.09	17.05	31.54	15.21
3	69.00	96.58	31.00	3.42	97.20	68.69	2.80	31.31	30.39	17.50
4	72.95	96.84	27.05	3.16	96.81	81.61	3.19	18.39	30.68	19.39
5	70.10	96.21	29.90	3.79	97.37	75.77	2.63	24.23	30.01	20.00
6	74.68	96.72	25.32	3.28	95.06	77.89	4.94	22.11	30.97	19.67

In all, the differences in the composition of raw material are small except for the fat content. However, comparing the reduction in fat between wet rendering and autoclave rendering, it is obvious that the fat separated by autoclave rendering is far less than that in wet rendering. The autoclave rendering was done without stirring which may contribute to the low reduction in fat. In addition, the processing time was 20 min which may have not been long enough to achieve the same reduction in fat as that obtained for wet rendering. To show a clear comparison of the reduction in fat, a line chart is given below.

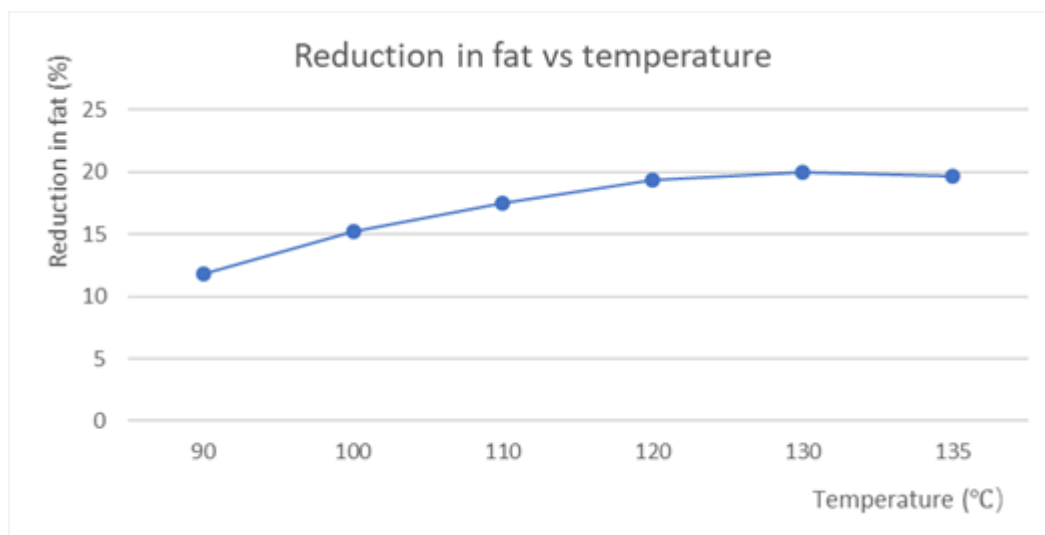


Figure 4.20: Reduction in fat of autoclave rendering

The reduction in fat grows with the temperature from 11.81% to 20.00%. However, after 110°C, the growth rate slowed down from 17.50% and reaches a peak at 130°C. Perhaps there is a higher temperature that will give a higher fat release however due to the limitation of the autoclave and the probable cost of the actual production industry, there is no need to investigate higher rendering temperatures. 110°C would be a suitable rendering temperature to make a good koi carp oil yield.

Overall, to get a better yield of by-product (such as koi carp oil) while producing koi carp meal, the appropriate rendering time is 20 to 40 min at 110°C, and the appropriate technology appears to be wet rendering because it gave a higher reduction in fat in the meal.

4.2 Pet food making and taste testing

Dry pet food was made from koi carp meal and minced chicken breast meat. Pictures of koi carp meal, dry pet food (nibbles) and wet pet food are shown in Figures 4.21 to 4.23.



Figure 4.21: Koi carp meal



Figure 4.22: Dry pet food



Figure 4.23: Wet pet food

The dry pet food had a powerful salty fishy smell which was similar to the koi carp meal but stronger. The dry pet food containing a higher proportion of koi carp meal was hard and smelt poor. High chicken content produced a better odour. The wet pet food cooked by steaming had a slightly pleasant scent of food. Consequently, it seems koi carp is suitable for low-temperature processing methods. The results from taste testing with cats is shown below in Figures 4.24 and 4.25.



Figure 4.24: Dry pet food taste testing result

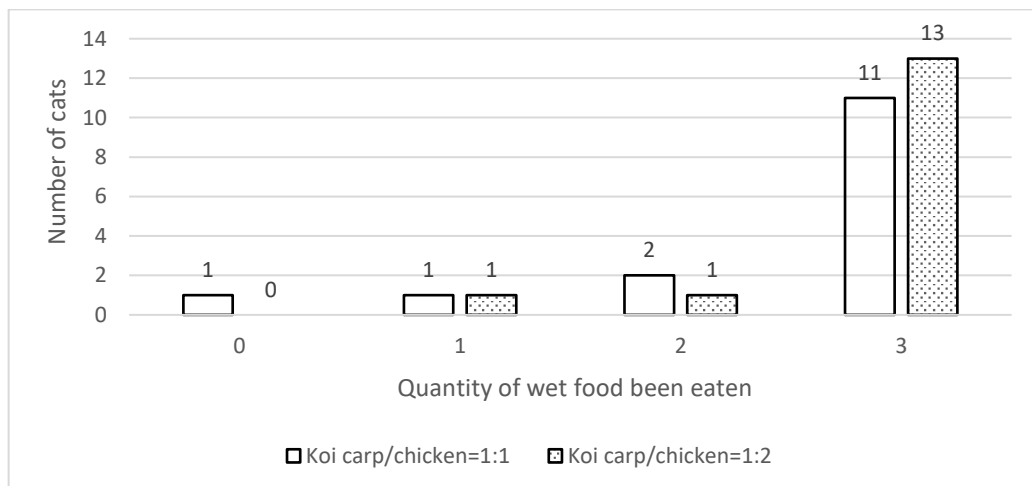


Figure 4.25: Wet pet food taste testing result

The taste testing was done in two groups: high koi carp meal content group (group 1) and the low koi carp meal content group (group 2). From the histogram, it is clear to see only one cat ate all the nibbles in group 1. This cat did not smell for a long time before eating. One more cat ate all the five nibbles in group 2. Four cats refused to have a taste of the nibbles introduced in group 1 while two cats refused the food in group 2. Two cats which in group 2 had one nibble and did not eat anymore when they found the nibbles hard to chew. Three cats tasted two nibbles in group 1 and five in group 2. The number of cats that tasted more than two nibbles were six and seven respectively in group 1 and 2. One-third of the cats were hesitating and unwilling to eat much of the high fish meal content nibbles as the poor odour and the number (six) did not improve a lot when facing the low koi carp meal content nibbles. But two more cats tried two nibbles in group 2.

Generally, the odour produced by koi carp meal heated under high temperature can strongly influence the palatability of dry pet food. Both kinds of nibbles did not perform well in taste testing, but the nibbles with less koi carp content seemed to be more acceptable. The dry pet food which contained more koi carp meal was harder and less welcomed. If koi carp meal can be used in pet food making in the future, the content of koi carp meal should be low and more ingredients are suggested to be added to balance, weaken and conceal the odour.

Another possibility of the low acceptance of the dry food is the cooking method. The important part of the commercial cooking method of dry pet food is the expansion of the paste after being extrusion cooked. Thus, the nibbles become crispy and light weight and reduces the raw material cost at the same time. Extrusion cooking can make a good food texture. The method used in this research was baking, which although it is a common method for making homemade pet food, the palatability could be influenced.

The taste testing of wet food showed a good result (Figure 4.25). The different proportions of koi carp did not influence the palatability. Both kinds of wet food were welcomed by cats. There was only one cat that did not eat the food in two groups of testing. Each group had one cat that only took one piece of food. Most cats (eleven to thirteen) ate all three pieces of food. Although the koi carp and chicken wet food performed good, there was a serious problem. The processing

method of wet pet food could not smash all the bones in koi carp meat. These tiny bones may be a threat to feline health. The advantages and disadvantages of making dry pet food and wet pet food of koi carp are summarized in Table 4.36.

Table 4.36: Advantages and disadvantages of dry pet food and wet pet food

	Advantages	Disadvantages
Dry pet food	<ul style="list-style-type: none"> ● Can produce by-product when making koi carp meal ● Koi carp meal is easy to store 	<ul style="list-style-type: none"> ● Poor odour ● Hard to chew
Wet pet food	<ul style="list-style-type: none"> ● Good scent ● Nice palatability ● Simple production process 	<ul style="list-style-type: none"> ● Contains tiny bones

4.3 Acceptance survey

The results of questionnaire survey are shown in Figures 4.26-4.28. In the acceptance survey, 61% of the participants (37 people) knew that koi carp was a pest fish in New Zealand. This number is not satisfactory. If many people do not know how the koi carp is destroying the aquatic environment, they may not pay attention to protecting the rivers, release captured fish and not support eradication or control. More publicity and education are needed to enhance the whole awareness of the crisis in the water.

No one has ever eaten koi carp. This result showed that eating koi carp is quite unpopular in New Zealand. The bony nature of the fish and muddy smell make the koi carp much less delicious than saltwater fish. As koi carp is a popular food in Asian, the reason why it cannot be accepted in New Zealand may be in the method of cooking. If a new, easy and good cooking method can be found and spread, eating koi carp may be possible.

56% of people own pets. In this group of people, all of them had fed their pets fish or pet food containing fish products before. The feedback on the food was good. Two of them were unaccepting of pet food made from koi carp because they were worried about the palatability. Of the 44% of people who have no pets, three of

them chose “No” for question 6. They thought it depended on the smell, the taste, the quality and so on. If pet food made from koi carp can be on the market in the future, it will be surely be tested and developed before going to the market.

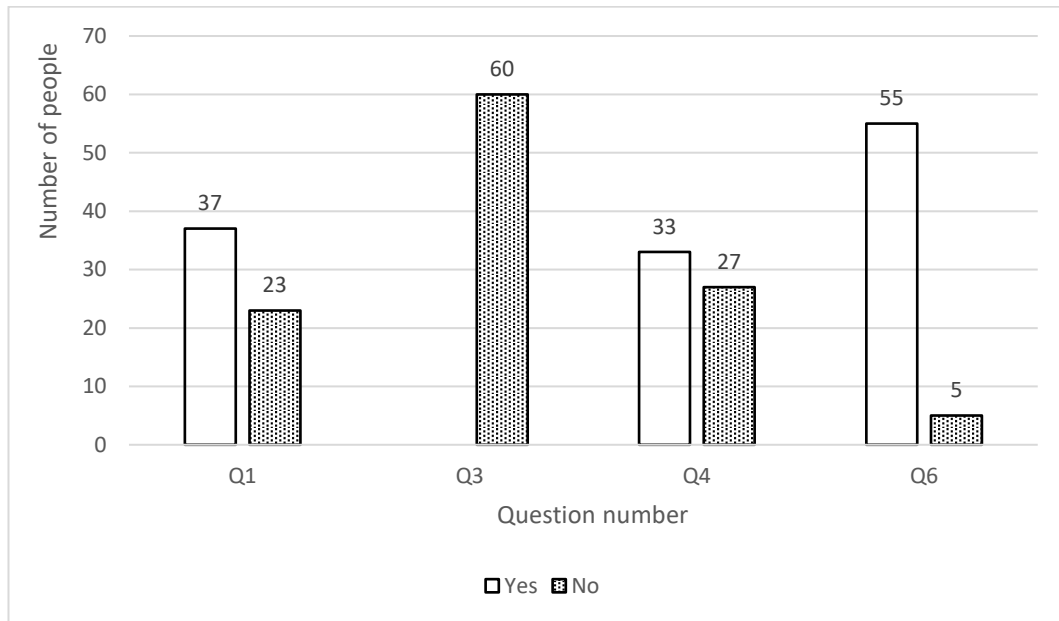


Figure 4.26: Results of question 1, 3, 4 and 6 (Yes/No)

1. *Do you know koi carp is an invasive fish species in New Zealand?*
3. *Have you ever eaten carp?*
4. *Do you have pets?*
6. *From your point of view, do you think the pet food that contains koi carp products is acceptable?*

Question 2 was a multiple choice question:

Question 2: What do you think is a good method to handle the captured koi carp?

- *Bury*
- *Eat*
- *Animal feed*
- *Plant fertilizer*
- *Release back*
- *Make other products (oil, gelatin, etc.)*

Results showed that most people thought good methods to handle the koi carp to produce an animal feed (26 answers) or plant fertilizer (20 answers) (Figure 4.27). There were eleven “Bury” answers. Three participants thought that the captured koi carp could be consumed by eating.

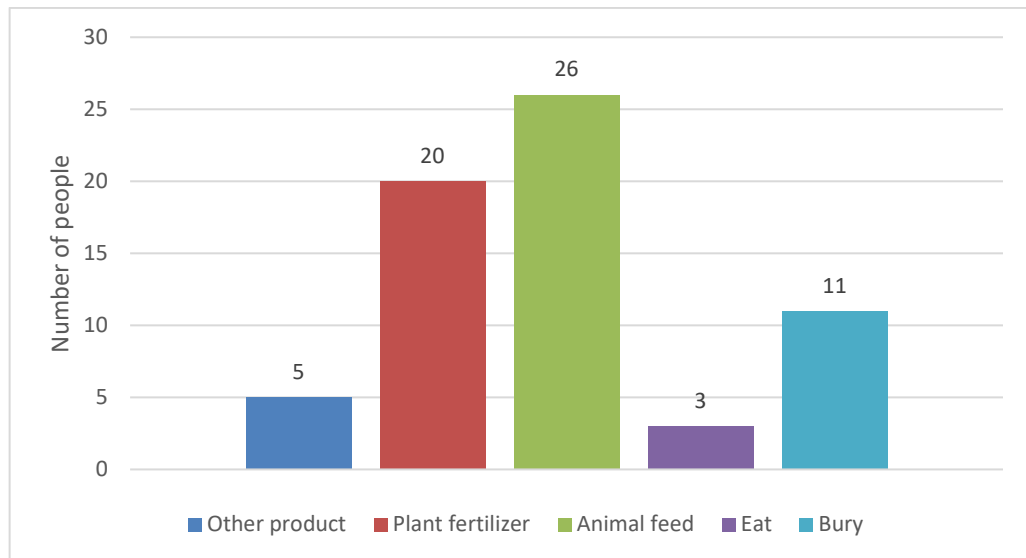


Figure 4.27: Result of question 2

Question 7 was also a multiple choice question:

Question 7: If a new pet food product that contains carp products comes out, will you buy for your per (if you have pets)?

- *Yes, I'll have a try.*
- *Maybe try later if the comments are good.*
- *Not sure.*
- *Never, I cannot accept this product.*

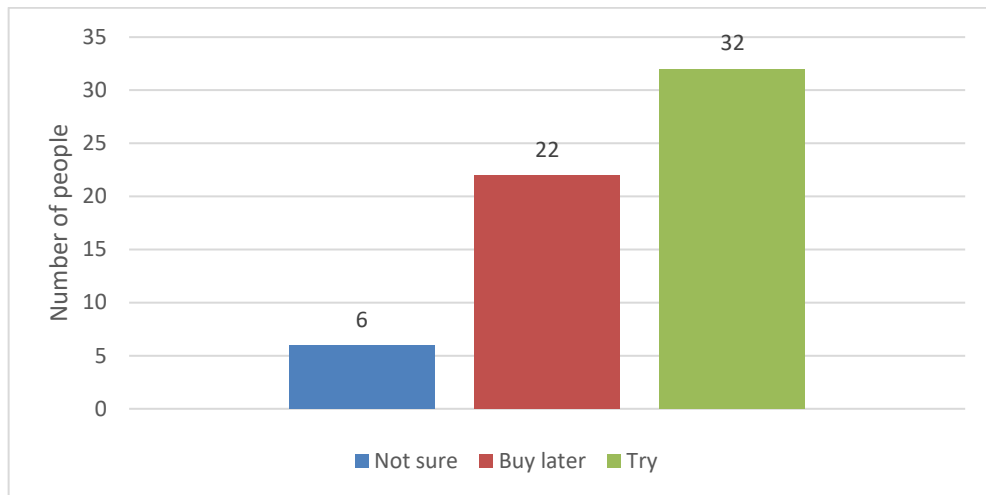


Figure 4.28: Result of question 7

No one determinedly showed that they would not buy koi carp pet food. 32 people said they would try the new pet food. People like them would be the pioneers, they represent the most open-minded people who feel pet food made from koi carp would be acceptable. 22 participants would maybe try the pet food later if the comments were good. These people showed a neutral attitude about the new pet food, but they did not refuse it. The rest of the people felt it was hard to decide and they were not sure if they would buy it.

From the small street survey, we can see most participants here are open-minded to a new pet food. Most of them would like to have a try. If the food has good palatability and quality, it may be well accepted.

4.4 Economic Profit Estimation

To decide how many fish can be captured for the industry per year, the growth rate of koi carp biomass is needed. The biomass of a species in nature grows following a logistic curve (Figure 4.29). The growth rate starts from a low value because of the population at that time is not enough for large scale reproduction. Then the growth rate and biomass increase rapidly until resources in the environment cannot support so many individuals, so the growth rate of the species slows down and the biomass reaches a steady state (Weatherley *et al.*, 1987). This maximum biomass is the carrying capacity of the environment.

The average biomass carrying capacity for koi carp in the Waikato region, in particular the Waikare, Whangape, Ngaroto, Waahi lakes by Huntly, is estimated to be around 200 kg/hectare (Hicks *et al.*, 2015). In the largest lake the Lake Waikare, there was no specific estimation of the koi carp biomass, but it was speculated to be a similar number to nearby Lake Ōhinewai which had 374 kg/hectare (Hicks *et al.*, 2015 & Piddock, G., 2018). The estimated population of koi carp in Lake Waikare is 700,000 (Clarke, M., 2018), and given that Lake Waikare has an area of 3,442 (Waikato Regional Council) that is 200 koi carp per hectare. With an average size of koi carp being around 1.5 kg per fish, that is 300 kg biomass per hectare. Overall, 200 kg/hectare seemed a sensible biomass carrying capacity to use.

It was estimated that from introduction of the fish to the lake, it took the koi carp 20 years to reach the carrying capacity of the lakes. The logistic curve and the growth rate curve of koi carp are shown below (Figure 4.29 and Figure 4.30).

The equation of the logistic curve is (Ricker W.E., 1975):

$$B = \frac{B_{\infty}}{1 + e^{-k(t-t_0)}}$$

B = biomass (stock size)

B_{∞} = maximum biomass

k = instantaneous rate of increase of stock at densities approaching zero

t = time

t_0 = a constant that adjust the time scale to an origin at the inflection point of the curve

The growth rate curve is the tangent to logistic curve. The equation is (Weatherley *et al.*, 1987):

$$\frac{dN}{dt} = r N \left(\frac{K - N}{K} \right)$$

$\frac{dN}{dt}$ = rate of change (growth rate)

r = exponent for rate of increase in size or number

N = size (biomass) of the growing population

K = maximum biomass

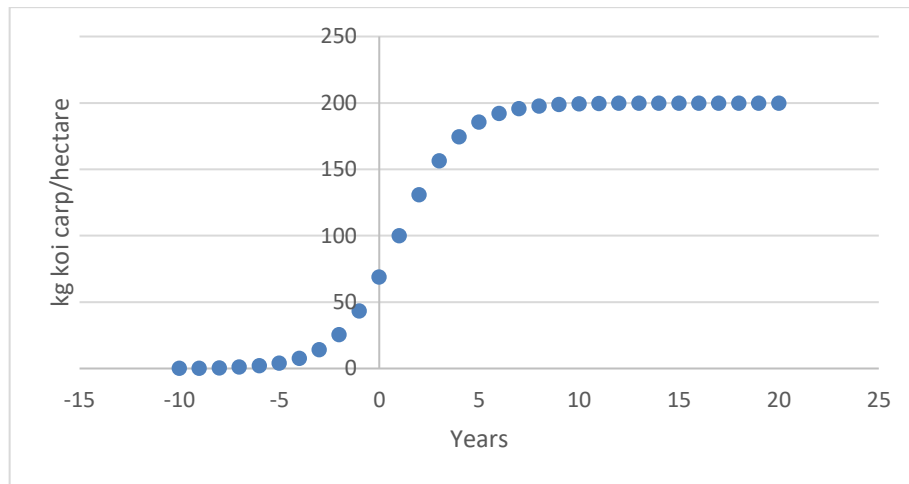


Figure 4.29: Logistic curve of koi carp

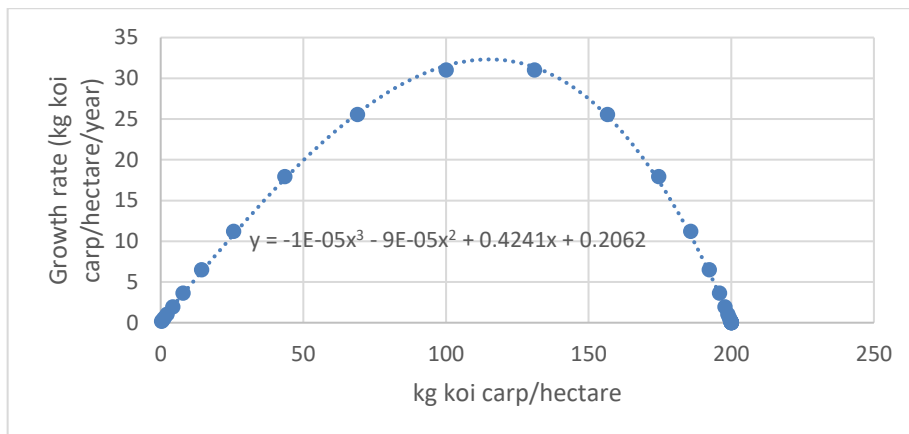


Figure 4.30: Growth rate of koi carp

The mass of the captured koi carp affects the growth rate, therefore the biomass of the koi carp in the next year is affected. If the mass of koi carp captured is more

than that of the new koi carp biomass produced, the biomass of the koi carp will decrease. Capturing the appropriate quantity of koi carp in the highest growth rate stage can maintain biomass at a stable level with the highest yields of koi carp.

At the carrying capacity, the mass of new koi carp reproduced every year is equal to the dead koi carp. The growth rate of koi carp is approximately 0. The highest growth rate of 31-32 kg/hectare/year appears to be at a density of 100 kg/hectare (Figure 4.30), which equates to 165 tonnes of koi carp per year (Table 4.37). The koi carp captured at this rate would maintain a steady state koi carp biomass of 140 kg/hectare (Figure 4.31).

Figure 4.31 below shows how mass of koi carp captured per year influences the biomass of koi carp. The calculation and equation are as follows:

$$\text{Koi carp end of the year} = \text{Total koi carp} - \text{Koi carp harvested}$$

$$\text{Total koi carp} = (\text{Mass koi carp per hectare} + \text{Growth per hectare per year}) \times 5500$$

The growth rate of each year is changing with the mass of koi carp per hectare that year. From the equation shown in Figure 4.30, the growth rate at different koi carp densities can be calculated. At a harvesting rates greater than 175 tonnes per year, the koi population reduces to zero after 40 years at 185 tonnes per year, the time taken to decline reducing with increased harvesting rate.

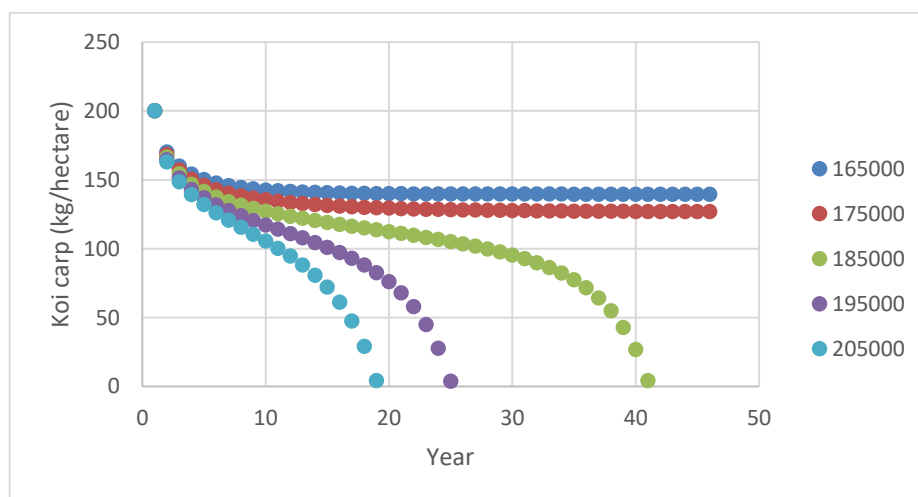


Figure 4.31: Biomass of koi carp when different mass of koi carp captured per year

Based on a koi carp harvesting rate of 165 tonnes per year and Figure 4.30, some basic calculations around koi carp reproduction was carried out (Table 4.37). It was estimated that there were 367 thousand koi carp assuming an average size of 1.5 kg per carp, of which half are female. Assuming breeding happens 1.5 times a year on average, each female with 100,000 eggs, and a fertilisation rate of 0.75, the amount of eggs that actually grow to full sized fish is very small (1 in every 62,500 reach maturity). Approximately 110,000 koi carp would be captured each year.

Table 4.37: Reproduction of koi carp and mass of koi carp captured

Area of Waikato 4 big lakes (Waikare, Whangape, Ngaroto, Waahi) (hectares)	5500	(Hamilton <i>et al.</i> , 2010; Hicks & Ling, 2015)	Waikare: 3442 hectares Whangape: 1450 hectares Waahi: 522 hectares Ngaroto: 108 hectares
Density of koi carp with highest growth rate (kg per hectare)	100		
Total mass of koi carp (kg)	550000		Area × Density
Average size of a koi carp (kg)	1.5		
Number of koi carp based on average size	366666		Total mass of koi carp / Average size of a koi carp
Ratio of female koi carp	0.5	(Tempero <i>et al.</i> , 2006)	
Number of female koi carp	183333		Number of koi carp based on average size × Ratio of female koi carp
Breeding cycles per year (on average)	1.5	(Linhart <i>et al.</i> , 1995; Brown <i>et al.</i> , 2003; Tempero <i>et al.</i> , 2006)	
Number of eggs per kg female fish	100000	(Brown <i>et al.</i> , 2003; Tempero <i>et al.</i> , 2006)	
Fertilisation rate (ratio fertilized)	0.75	(Linhart <i>et al.</i> , 1995; Bozkurt & Ogretmen, 2012)	

Number of eggs fertilised	1375000000		Breeding cycles per year × Number of eggs per kg female fish × Fertilisation rate
Ratio of fertilised eggs that survive to fully grown fish	0.000016		
Number of eggs that grow to full size	220000		Number of eggs fertilised × Ratio of fertilised eggs that survive to fully grown fish
Time taken to reach full size (years)	3		
Mass of new koi carp per year in the 4 lakes in Waikato region (kg/hectare)	30		
Mass of new koi carp per year (kg)	165000		Mass of new koi carp per year in the 4 lakes in Waikato region × Area of Waikato 4 big lakes
Ratio of koi carp captured to new koi carp produced	1		
Mass of koi carp captured per year (kg)	165000		
Mass koi carp remaining at end of year (kg)	550000		Mass of new koi carp per year + Total mass of koi carp - Mass of koi carp captured per year
Number of koi carp captured	110000		Mass of koi carp captured per year / Average size of a koi carp

Table 4.38: Weight ratio of koi carp body parts

	Fraction
Skin/scales	0.01
Fillet	0.36
Frame/head	0.4
Offal	0.23

For the economic analysis, it was assumed that koi carp fillets would be used for the edible pet food (36% of the koi carp body mass) and the remainder would be used for the inedible meal. Wet rendering would be used at a rendering time of 40 minutes with a ratio of 1 kg of water per kg of fish. Yields such as mass of wet meal, oil and stickwater and evaporative losses are listed in Table 4.39. Other parameters such as solids contents of the different fractions and final products; heat capacities; energy prices and labour costs, cooking, and electrofishing boat costs, and other economic calculations are listed in Tables 4.40 to 4.59. Economic results are listed in Tables 4.60 and 4.61.

Table 4.39: Parameters of rendering koi carp (edible fillet and inedible parts)

Edible rendering (wet)	Mass of water required per kg fillet	1	
	Mass of wet meal per kg fillet	0.83	
	Mass of oil per kg fillet	0.015	
	Mass of water lost to evaporation per kg fillet	0.54	Conditions in wet rendering for 40 min
	Mass of stickwater per kg fillet	0.615	Mass of water required + 1 – (Mass of wet meal + Mass of water lost to evaporation + Mass of oil)
Inedible rendering (wet)	Mass of water required per kg inedible fish	1	
	Mass of wet meal per kg inedible fish	0.85	Weight loss of bone is less
	Mass of oil per kg inedible fish	0.02	Bones, offal, roes contain more oil than fillet
	Mass of water lost to evaporation per kg inedible fish	0.54	
	Mass of stickwater per kg inedible fish	0.59	Mass of water required + 1 – (Mass of wet meal + Mass of water lost to evaporation + Mass of oil)

Table 4.40: Solids content fraction of wet meal, stickwater, chicken meal, nibbles and raw chicken breast

Meal (kg/kg wet meal)	0.25	
Stickwater (kg/kg stickwater)	0.04	
Chicken meal (kg/kg chicken)	0.9	("Chicken Meal" n.d.)
Cooked nibbles (kg/kg nibble)	0.92	(Leonardi, 2013)
Chicken breast (kg/kg chicken)	0.3	("Chicken Meal" n.d.)

Table 4.41: Heat capacity of water, fish, fish meal and nibbles

Heat of evaporation for water (kJ/kg)	2300	("Water - Heat of Vaporization" n.d.)
Heat capacity of fish meat (kJ/kg.K)	3.6	("Specific Heat of Food and Foodstuff" n.d.)
Heat capacity of chicken meat (kJ/kg.K)	3.68	("Specific Heat of Food and Foodstuff" n.d.)
Heat capacity of canned fish (kJ/kg.K)	3.35	("Specific Heat of Food and Foodstuff" n.d.)
Heat capacity water (kJ/kg.K)	4.125	
Heat capacity fish meal (kJ/kg.K)	3.026	("Common food heat capacity", 2019)
Heat capacity nibble mixture (kJ/kg.K)	3.18	

Table 4.42: Energy price and labour cost

Natural gas (MJ/kg)	45.2	("Heat Values of Various Fuels" n.d.)
Heating efficiency	0.8	
Fish skinned and filleted per person per hour	300	12 s / fish
Labour cost (\$/hour)	23	The lowest salary per hour is 17.7 \$/h, technical job is 24.29 \$/h
Electricity costs (\$/kg fish in dry pet food processed)	0.03	
Electricity costs (\$/kg fish in wet pet food processed)	0.06	
Miscellaneous costs (\$/kg fish processed)	0.05	

Table 4.43: Parameters of steaming/boiling wet pet food

Steamed chicken after steaming/boiling (kg/kg raw chicken)	0.7	(Sun, Y., & Fan, S., 2019)
Water evaporated (kg/kg water added)	0.7	
Mass water added (kg/kg raw food)	1	

Table 4.44: Working hours and labour cost

Hours per day	8	9:00 am – 5:00 pm
Days per year operation	240	
Hours per year operation	1920	
Number of operators	1	Controlling machine
Operator costs (\$/year)	44160	
Throughput (kg fish/hour)	85.9	Mass of koi carp captured per year / Hours per year operation
Throughput (kg fish/day)	687.5	
Skinning and filleting (hrs/year)	366.7	Number of koi carp captured / Fish skinned and filleted per person per hour
Labour costs (\$/year)	8433.3	Skinning and filleting hours × Labour cost per hour

Table 4.45: Workload and cost of electrofishing boat

Electrofishing boat capture (kg/hour)	250.0	
Hours required per day	2.8	Throughput (kg fish/day) / Electrofishing boat capture
Fishing crew per boat	3.0	
Additional hours per day (transport to and from)	2.0	(Hours required per day + Additional hours per day) × Fishing crew per boat × Days per year operation
Total labour hours required	3420.0	
Labour costs for boat per year (\$ per year)	78660.0	Total labour hours required × Labour cost (\$/hour)

Table 4.46: Cost of edible rendering

Edible rendering (kg per year)	59400.0	Mass of koi carp captured per year × meat fraction of a koi carp
Water required per year (kg)	59400.0	Edible rendering × Mass of water required per kg fillet
Wet meal produced per year (kg)	49302.0	Edible rendering × Mass of wet meal per kg fillet
Oil produced per year (kg)	891.0	Edible rendering × Mass of oil per kg fillet

Mass of water evaporated during rendering (kg per year)	32076.0	Edible rendering × Mass of water lost to evaporation
Stickwater produced per year (kg)	36531.0	Edible rendering × Mass of stickwater per kg fillet
Starting temperature (°C)	20.0	
Final temperature (°C)	96.0	
Heating (kJ per year) (assuming no heat recovery)	108648540.0	$(96 - 20) \times 4.125 \times \text{Edible rendering} + (96 - 20) \times \text{water required} \times 4.125 + \text{Mass of water evaporated during rendering} \times 2300$ Energy prices. (n.d.)
Heat required (kJ per year including losses)	135810675.0	Heating / Heating efficiency
Natural gas required (kg/year)	3004.7	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	("Energy prices", 2019)
Cost of natural gas per year (\$ per year)	1006.4	Heat required / $10^6 \times$ Price of natural gas
Price of water (\$/kg)	0.0015	("Water and wastewater price changes effective 1 July 2018", 2018)
Water costs per year (\$/year)	89.1	Water required per year × Price of water

Table 4.47: Cost of koi carp meal drying for dry pet food production

Final solids content (kg/kg meal)	0.92	(Windsor, M. L. n.d.)
Mass meal for drying (kg per year)	49302.0	Wet meal produced per year
Mass dry meal per year (kg per year)	12325.5	Mass meal for drying × Solids content of wet meal
Mass dried meal (kg per year)	13397.3	Mass dry meal per year / Final solids content
Water evaporated (kg per year)	35904.7	Mass meal for drying - Mass dried meal
Starting temperature (°C)	80.0	
Final temperature (°C)	100.0	
Heating (kJ per year) (assuming no heat recovery)	85564607.0	$(100 - 80) \times \text{Mass meal for drying} \times 3 + \text{water evaporated} \times 2300$
Heat required (kJ per year including losses)	106955758.8	Heating / Heating efficiency
Natural gas required (kg/year)	2366.3	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	
Cost of natural gas per year (\$ per year)	792.5	Heat required / $10^6 \times$ Price of natural gas

Table 4.48: Cost and revenue of dry pet food production

Mass chicken meal added per kg fish meal	0.7	
Mass chicken meal required (kg per year)	9378.1	Mass of dried meal × Mass chicken added per kg meal
Mass dry chicken meal per year (kg/year)	8440.3	Mass chicken meal required × solids content of chicken meal
Mass of water added (kg/year)	19694.0	Mass dry chicken meal per year / Solids content of chicken breast - Mass dry chicken meal per year In this project, raw chicken breast was used and no water added, here the chicken resource is replaced by chicken meal to reduce cost.
Mass of dry nibbles per year (kg per year)	20765.8	Mass dry fish meal + Mass dry chicken meal
Mass of nibbles per year (kg/year)	22571.5	Mass of dry nibbles per year / Cooked nibbles solids content
Cost of chicken meal (\$/kg)	0.8	Mass meal for drying - Mass dried meal
Cost of chicken meal per year (\$ per year)	7502.5	
Water evaporated (kg/year)	19897.9	Mass dry fish meal per year + Mass dry chicken meal per year + Mass water added – Mass of nibbles per year
Starting temperature (°C)	20.0	
Final temperature (°C)	150.0	
Heating (kJ per year) (assuming no heat recovery)	51941810.8	Mass of nibbles per year × 2.105 × (150 - 20) + Water evaporated × 2300
Heat required (kJ per year including losses)	64927263.4	Heating / Heating efficiency
Natural gas required (kg/year)	1436.4	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	
Cost of natural gas per year (\$ per year)	481.1	Heat required / 10 ⁶ × Price of natural gas
Nibble bag size (kg/bag)	1.0	
Nibble bags produced per year	22571.5	
Bag price (\$/bag)	0.1	
Cost of bags per year (\$ per year)	2804	
Sales price per bag of nibbles (\$/bag)	4.0	
Bags packed per hour	1000.0	
Labour costs per year (\$ per year)	519.1	Nibble bags produced per year / Bags packed per hour × Labour cost per hour
Price of water (\$/kg)	0.0015	Water and wastewater price changes effective 1 July 2018. (n.d.)

Water costs per year (\$/year)	29.5	Price of water × Mass water added per year
Revenue per year from petfood (\$/year)	90286.0	

Table 4.49: Cost and revenue of crude koi carp oil

Sales price of fish oil (\$ per kg)	3.6	The crude fish oil is much cheaper than fish oil end product
Volume product sold (kg/unit)	0.5	
Number of units sold per year	1782.0	Oil produced per year / Volume product sold
Cost bottles (\$ per bottle)	0.45	("How much does it cost to manufacture a plastic bottle", 2016)
Cost of bottles per year (\$ per year)	996.3	
Bottles packed per hour	1000.0	
Labour costs per year (\$ per year)	41.0	Number of units sold per year / Bottles packed per hour × Labour cost per hour
Revenue per year from fish oil (\$ per year)	3207.6	Oil produced per year × Sales price of fish oil

Table 4.50: Cost and revenue of making stickwater powder (stickwater option 1)

Mass of stickwater per year (kg)	36531.0	
Starting concentration of stickwater (kg solids per kg stickwater)	0.040	
Final concentration of stickwater (kg solids per kg stickwater)	0.9	
Mass dry stickwater produced (kg/year)	1623.6	Mass of stickwater per year × Starting concentration of stickwater / Final concentration of stickwater
Mass water evaporated (kg/year)	34907.4	Mass of stickwater per year - Mass dry stickwater produced
Starting temperature (°C)	80.0	
Final temperature (°C)	100.0	
Heating (kJ per year) (assuming no heat recovery)	83300827.5	Mass of stickwater per year × $4.125 \times (100 - 80) + \text{Mass water evaporated} \times 2300$

Heat required (kJ per year including losses)	104126034.4	Heating / Heating efficiency
Natural gas required (kg/year)	2303.7	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	
Cost of natural gas per year (\$ per year)	771.6	Heat required / $10^6 \times$ Price of natural gas
Stickwater powder price (\$/kg)	0.8	
Stickwater revenue (\$ per year)	1298.9	
Stickwater gross profit (\$/year)	527.3	

Table 4.51: Cost of wastewater treatment of stickwater (stickwater option 2)

Mass of stickwater per year (kg)	36531.0	
Mass solids in stickwater (kg/year)	1461.2	Mass of stickwater per year \times Stickwater solids content
Waste water treatment cost (\$/kg solids)	0.0026	
Wastewater treatment cost (\$/year)	3.8	("Water and wastewater price changes effective 1 July 2018", 2018)

Table 4.52: Cost of inedible koi carp parts rendering

Inedible rendering (kg per year)	105600.0	Mass of koi carp captured per year – edible rendering
Water required per year (kg)	105600.0	Inedible rendering \times Mass of water required per kg fillet
Wet meal produced per year (kg)	87648.0	Inedible rendering \times Mass of wet meal per kg fillet in inedible rendering
Oil produced per year (kg)	2112.0	Inedible rendering \times Mass of oil per kg fillet
Mass of water evaporated during rendering (kg per year)	57024.0	Inedible rendering \times Mass of water lost to evaporation
Stickwater produced per year (kg)	64416.0	Inedible rendering \times Mass of stickwater per kg fillet
Starting temperature (°C)	20.0	
Final temperature (°C)	96.0	
Heating (kJ per year) (assuming no heat recovery)	193152960.0	$(96 - 20) \times 4.125 \times$ Inedible rendering + $(96 - 20) \times$ water required $\times 4.125$ + Mass of water evaporated during rendering $\times 2300$
Heat required (kJ per year including losses)	241441200.0	Heating / Heating efficiency
Natural gas required (kg/year)	5341.6	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	

Cost of natural gas per year (\$ per year)	1789.1	Heat required / $10^6 \times$ Price of natural gas
Price of water (\$/kg)	0.015	("Water and wastewater price changes effective 1 July 2018", 2018)
Water costs per year (\$/year)	1584.0	Water required per year \times Price of water

Table 4.53: Cost and revenue of inedible koi carp parts meal drying

Final solids content (kg/kg meal)	0.92	
Mass meal for drying (kg per year)	89760.0	Wet meal produced per year
Mass dry meal per year (kg per year)	22440.0	Mass meal for drying \times Solids content of wet meal
Mass dried meal (kg per year)	24391.3	Mass dry meal per year / Final solids content
Water evaporated (kg per year)	65368.7	Mass meal for drying - Mass dried meal
Starting temperature ($^{\circ}$ C)	80.0	
Final temperature ($^{\circ}$ C)	100.0	
Heating (kJ per year) (assuming no heat recovery)	153985075.2	$(100 - 50) \times$ Mass meal for drying \times 3 + water evaporated \times 2300
Heat required (kJ per year including losses)	192481344.0	Heating / Heating efficiency
Natural gas required (kg/year)	4258.4	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	
Cost of natural gas per year (\$ per year)	1426.3	Heat required / $10^6 \times$ Price of natural gas
Sales price of meal (\$/kg)	0.8	("High protein fish meal for poultry" n.d.)
Revenue from meal (\$ per year)	19513.0	

Table 4.54: Cost and revenue of inedible koi carp parts crude fish oil

Sales price of fish oil (\$ per kg)	2.0	The crude fish oil is much cheaper than fish oil end product. Fish oil from the inedible fish part is cheaper.
Volume product sold (kg/unit)	0.5	
Number of units sold per year	4224.0	Oil produced per year / Volume product sold

Cost bottles (\$ per bottle)	0.45	
Cost of bottles per year (\$ per year)	2361	
Bottles packed per hour	1000.0	
Labour costs per year (\$ per year)	97.2	Number of units sold per year / Bottles packed per hour × Labour cost per hour
Revenue per year from fish oil (\$ per year)	4224.0	Oil produced per year × Sales price of fish oil

Table 4.55: Cost and revenue of making inedible koi carp parts stickwater powder (stickwater option 1)

Mass of stickwater per year (kg)	62304.0	
Starting concentration of stickwater (kg solids per kg stickwater)	0.04	
Final concentration of stickwater (kg solids per kg stickwater)	0.9	
Mass dry stickwater produced (kg/year)	2769.1	Mass of stickwater per year × Starting concentration of stickwater / Final concentration of stickwater
Mass water evaporated (kg/year)	59534.9	Mass of stickwater per year - Mass dry stickwater produced
Starting temperature (oC)	80.0	
Final temperature (oC)	100.0	
Heating (kJ per year) (assuming no heat recovery)	142070426.7	Mass of stickwater per year × $4.125 \times (100 - 80) + \text{Mass water evaporated} \times 2300$
Heat required (kJ per year including losses)	177588033.3	Heating / Heating efficiency
Natural gas required (kg/year)	3928.9	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	
Cost of natural gas per year (\$ per year)	1315.9	Heat required / $10^6 \times \text{Price of natural gas}$
Stickwater powder price (\$/kg)	0.8	
Stickwater revenue (\$ per year)	2215.3	
Stickwater gross profit (\$/year)	899.3	

**Table 4.56: Cost of wastewater treatment of inedible koi carp parts
stickwater (stickwater option 2)**

Mass of stickwater per year (kg)	62304.0	
Mass solids in stickwater (kg/year)	2492.2	Mass of stickwater per year × Stickwater solids content
Wastewater treatment cost (\$/kg solids)	0.0026	
Wastewater treatment cost (\$/year)	6.5	

Table 4.57: Revenue of rendering koi carp and making dry pet food (165000 kg koi carp captured per year)

Dry pet food sales (\$/year)	103828.9
Inedible meal sales (\$/year)	19513.0
Stickwater powder sales(\$/year)	1298.9
Inedible stickwater powder sales(\$/year)	2215.3
Edible oil sales (\$/year)	3207.6
Inedible oil sales (\$/year)	4224.0
Total revenue	134287.7

Table 4.58: Cost and profit of rendering koi carp and making dry pet food (165000 kg koi carp captured per year)

Labour (\$/year)	145154.4
Materials (\$/year)	15483.5
Natural gas costs (\$/year)	7255.3
Wastewater treatment (\$/year)	12.8
Water (\$/year)	2115.4
Electrical costs (\$/year)	6150
Miscellaneous costs (\$/year)	10250
Total costs (\$/year)	186421.4
Gross profit (\$/year)	-36405.1
Margin	-0.24

Table 4.59: Cost and revenue of wet pet food production

Mass raw chicken added per kg wet meal	2.0	
Mass chicken required (kg per year)	98604.0	Mass raw chicken added per kg wet meal × Wet meal produced per year
Mass of water added (kg/year)	147906.0	(Mass chicken required + Mass wet meal produced) × Water added per kg raw material
Mass of wet food per year (kg/year)	118324.8	Chicken after steaming × Mass chicken required + Wet meal produced per year
Cost of chicken (\$/kg)	12.0	
Cost of chicken per year (\$ per year)	1183248.0	Cost of chicken × Mass chicken required
Water evaporated (kg/year)	128633	Water evaporated per kg raw material × (Mass chicken required + Wet meal produced per year)
Starting temperature (°C)	20.0	
Final temperature (°C)	100.0	
Heating (kJ per year) (assuming no heat recovery)	280370613.6	Water evaporated × 2300 + (3.35 × Wet meal per year + 3.68 × Mass raw chicken added) × (100 – 20)
Heat required (kJ per year including losses)	350463267.0	Heating / Heating efficiency
Natural gas required (kg/year)	7753.6	Heat required / 1000 / Natural gas (MJ/kg)
Price of natural gas (\$/GJ)	7.41	
Cost of natural gas per year (\$ per year)	3226.5	
Wet food can size (kg/can)	0.1	
Can required per year	1183248.0	
Can price (\$/can)	0.5	
Cost of cans per year (\$ per year)	591624.0	Can required per year × Can price
Sales price per can (\$/can)	1.0	
Cans packed per hour	2000.0	
Price of water (\$/kg)	0.0015	
Water costs per year (\$/year)	221.9	
Revenue per year from pet food (\$/year)	1183248.0	

Table 4.60: Revenue of rendering koi carp and making wet pet food (165000 kg koi carp captured per year)

Wet pet food sales (\$/year)	1183248.0
Inedible meal sales (\$/year)	49866.7
Stickwater powder sales(\$/year)	1298.9
Inedible stickwater powder sales(\$/year)	2215.3
Edible oil sales (\$/year)	3207.6
Inedible oil sales (\$/year)	4224.0
Total revenue	1244060.4

Table 4.61: Cost and profit of rendering koi carp and making wet pet food (165000 kg koi carp captured per year)

Labour (\$/year)	131391.5
Materials (\$/year)	1775172.3
Natural gas costs (\$/year)	6930.7
Wastewater treatment (\$/year)	10.3
Water (\$/year)	974.3
Electrical costs (\$/year)	99000
Miscellaneous costs (\$/year)	8250
Total costs (\$/year)	2021729.0
Gross profit (\$/year)	-777668.
Margin	-0.63

To breakeven when 165 tonnes of koi carp is captured per year, the dry pet food needs to be sold at just under \$6 per kg (Figure 4.32). This decreases with increased harvesting to \$5 per kg at 205 tonnes of koi carp. If the sales price of the dry pet food is \$8/kg, the profit obtained processing 165 tonnes of fish per year is \$52K, while at 205 tonnes per year, it is \$83K. Dry pet food at the supermarket retails for \$5 to \$15 per kg, so the price of the koi carp pet food is reasonable if it can be sold directly to customers. The comparison of costs is given Figure 4.33, where labour is 80% of the total costs.

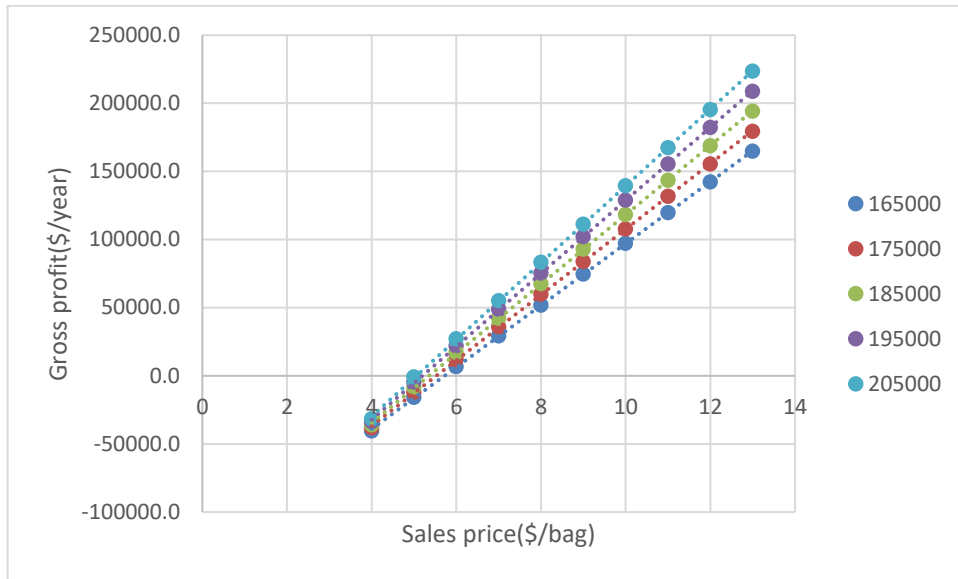


Figure 4.32: Gross profit of dry pet food sales price when different mass of koi carp captured

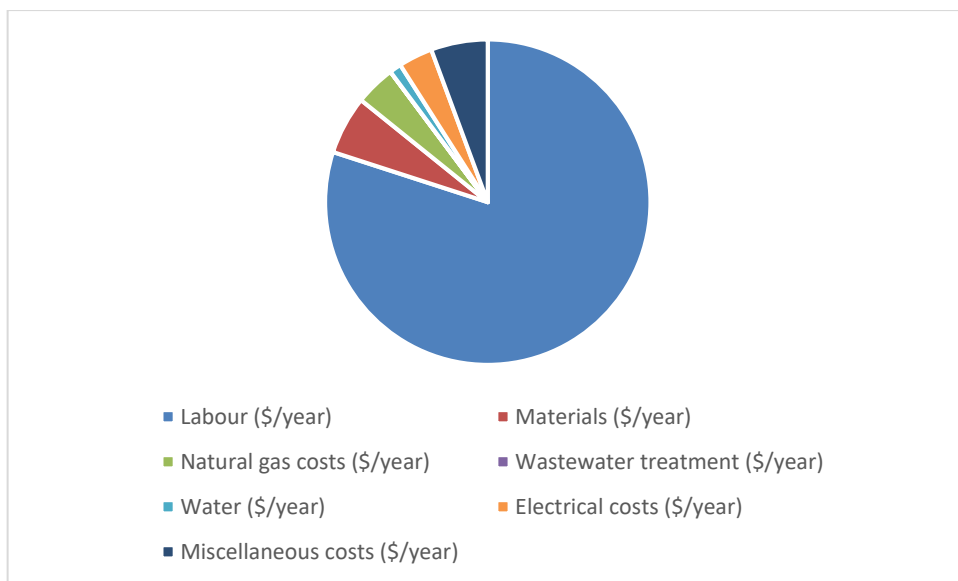


Figure 4.33: Cost composition of rendering koi carp and dry pet food making

Wet pet food production is much more profitable than dry pet food production. The price of each can of pet food to break even should be around \$1.7. This is an appropriate price for a 100 g can pet food (cans of pet food at the supermarket retail for between \$1.5 to 3 per can, but the size of the can varies). This is approximately

10 times the price of dry pet food on a per kg basis. The profit made at \$2 per can at 165 tonnes of fish per year is \$408K while at 205 tonnes of koi carp the profit is \$526K. For wet pet food processing, the labour cost was only 6% of the total costs, as an automated process needs to be used for canning the pet food, however this would increase capital costs.

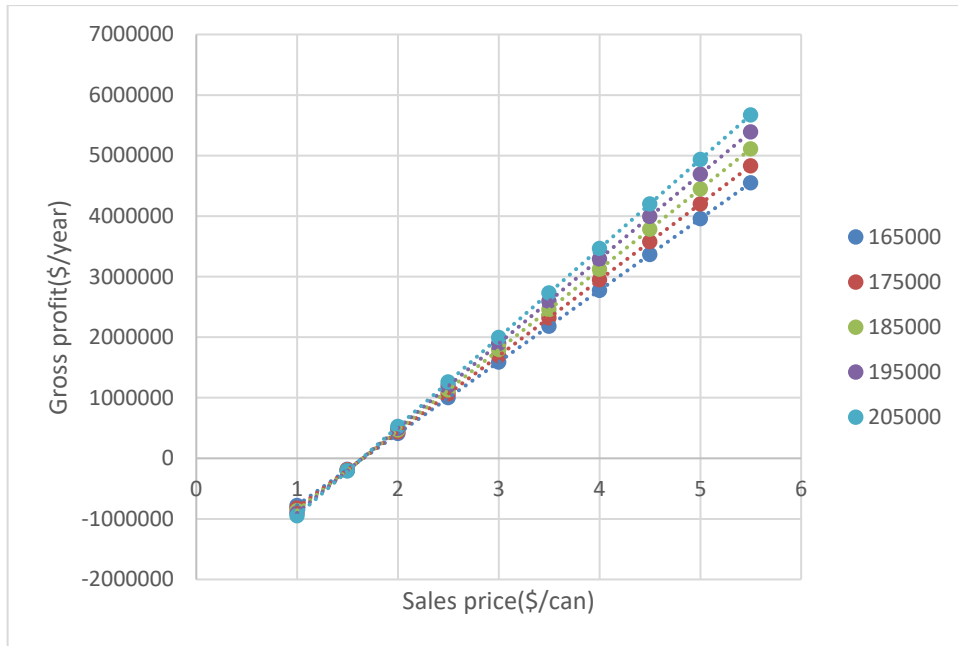


Figure 4.34: Gross profit of wet pet food sales price when different mass of koi carp captured

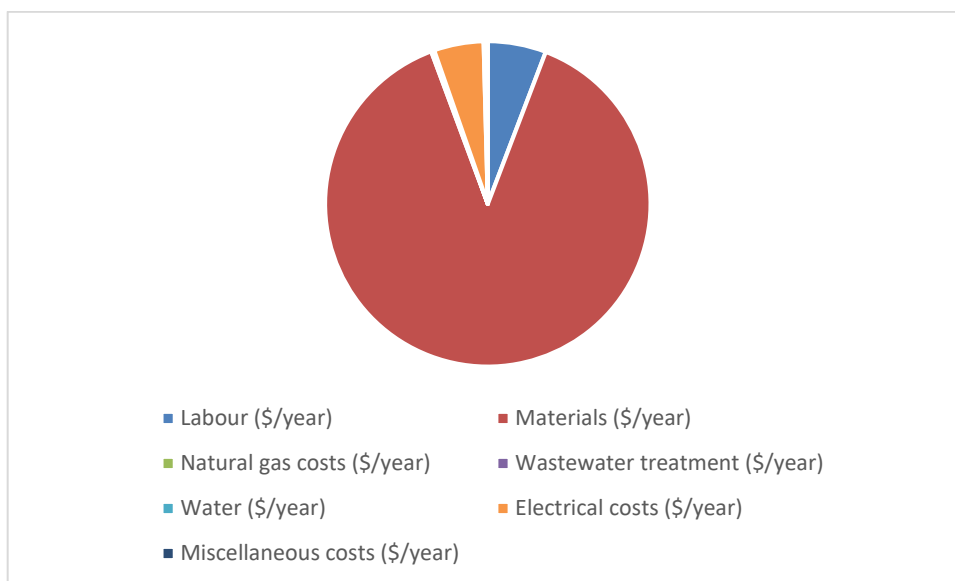


Figure 4.35: Cost composition of rendering koi carp and wet pet food making

The aim of pet food making is removing koi carp from the waterways. From Figure 4.31, if 165 tonnes of koi carp is captured per year, the biomass of koi carp will maintain a stable level which is not suitable for our purpose. Both dry and wet pet food production profit increases with increasing koi carp processing. The business would last 19 years if 205 tonnes of koi carp are captured per year, but it would become increasingly harder to find the fish, average fish body mass would decrease and labour costs would increase, so this would not be ideal. Therefore, for sustainable production, koi carp would need to be harvested at 165 to 170 tonnes per year which would bring the density of biomass down to 140 kg/hectare (Figure 4.31). The density of koi carp which cannot cause trouble for the aquatic environment is at most 100 kg/hectare (Hicks & Ling, 2015). At this biomass, 170 tonne of new koi carp is produced per year. If koi carp is captured at 205 tonne per year, after 12 years the biomass reduces to 100 kg/hectare. After this is reached, harvest should be dropped to 170 tonnes per year to maintain sustainable production and keeping the koi carp at a safe population density.

5 CONCLUSIONS

Koi carp is an invasive species fish in New Zealand that severely destroys the aquatic environment in the waterways in the Waikato region. The aim of the project was to look for a method that could make use of captured koi carp. The suitable use should be cheap, easy to operate and economic. Thus, rendering koi carp, making pet food and producing fish oil seemed to be feasible options. Wet rendering and autoclave rendering was examined for producing fish meal and oil under different processing conditions such as time, temperature and water content.

The water content of raw minced fish was around 69-77%, the solids content was between 23%-31%. Ash content was 6.2-7.4% of the dry solids and fat content between 13.7%-30%. Fish with a high fat content were females containing roe. The meal produced from wet rendering contained 22-28% solids, with 5-9% ash and 14-16% fat on a dry basis, while the stickwater contained 3% solids and 12-39% ash on a dry basis. Autoclave rendering produced a meal containing 26-30% solids, 3-5% ash and 30-31% fat on a dry basis and a stickwater containing 3.2% solids and 27-32% ash on a dry basis. Fat reduction in meal increased with rendering time for wet rendering up to 30% at 40 minutes rendering time, while only a 20% reduction in fat was achieved for autoclave rendering. Wet rendering was selected for producing meals.

Dry pet food and wet pet food was made by mixing rendered fish meal with chicken mince. The dry food was produced by baked while the wet food was produced by steaming. Taste testing showed that cats preferred wet pet food over the dry pet food. The dry pet food had a strong odour and poor palatability. Most cats in the taste testing hesitated to try or eat much of the dry food. It was hard for them to chew the nibbles. Less koi carp meal should be used to improve palatability. The majority of the wet pet food was consumed and it had a better odour.

A customer survey showed acceptance of koi carp for pet food was high. 92% of the participants felt they would buy or try later. People who have pets were more open-minded about using pet food made from koi carp.

An economic analysis showed that 165 tonnes of koi carp could be harvested per year from four Waikato lakes by Huntly, maintaining a biomass density of 140 kg/hectare, down from the current average density of around 200 kg/hectare. To reduce the density down to 100 kg/hectare, koi carp would need to be harvested at 205 tonnes per year for the first 12 years, reducing harvesting to 170 tonnes per year after this. Wet pet food production is much more profitable than dry pet food production. The price of each 100 g can of wet pet food to break even should be around \$1.7 which is comparable to supermarket prices. This is approximately 10 times the price of dry pet food on a per kg basis. The profit made at \$2 per can at 165 tonnes of fish per year is \$408K while at 205 tonnes of koi carp the profit is \$526K. Dry pet food needs to be sold at just under \$6 per kg to breakeven at 165 tonnes of koi carp per year. This decreases with increased harvesting to \$5 per kg at 205 tonnes of koi carp per year. If the sales price of the dry pet food is \$8/kg, the profit obtained processing 165 tonnes of fish per year is \$52K, while at 205 tonnes per year, it is \$83K. Dry pet food at the supermarket retails for \$5 to \$15 per kg.

Future work should include capital costing of equipment, and a more detailed analysis of operating costs.

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APPENDIX 1

TABLE 1 -- AAFCO Dog Food Nutrient Profiles				
Nutrient	Units DM Basis	Growth and Reproduction Minimum	Adult Maintenance Minimum	Maximum
Protein	%	22.0	18.0	
Arginine	%	0.62	0.51	
Histidine	%	0.22	0.18	
Isoleucine	%	0.45	0.37	
Leucine	%	0.72	0.59	
Lysine	%	0.77	0.63	
Methionine-cystine	%	0.53	0.43	
Phenylalanine-tyrosine	%	0.89	0.73	
Threonine	%	0.58	0.48	
Tryptophan	%	0.20	0.16	
Valine	%	0.48	0.39	
Fat	%	8.0	5.0	
Linoleic acid	%	1.0	1.0	
Minerals				
Calcium	%	1.0	0.6	2.5
Phosphorus	%	0.8	0.5	1.6
Ca:P ratio		1:1	1:1	2:1
Potassium	%	0.6	0.6	
Sodium	%	0.3	0.06	
Chloride	%	0.45	0.09	
Magnesium	%	0.04	0.04	0.3
Iron	mg/kg	80.0	80.0	3000.0
Copper	mg/kg	7.3	7.3	250.0
Manganese	mg/kg	5.0	5.0	
Zinc	mg/kg	120.0	120.0	1000.0
Iodine	mg/kg	1.5	1.5	50.0
Selenium	mg/kg	0.11	0.11	2.0

Vitamins				
Vitamin A	IU/kg	5000.0	5000.0	250000.0
Vitamin D	IU/kg	500.0	500.0	5000.0
Vitamin E	IU/kg	50.0	50.0	1000.0
Thiamine	mg/kg	1.0	1.0	
Riboflavin	mg/kg	2.2	2.2	
Pantothenic acid	mg/kg	10.0	10.0	
Niacin	mg/kg	11.4	11.4	
Pyridoxine	mg/kg	1.0	1.0	
Folic Acid	mg/kg	0.18	0.18	
Vitamin B12	mg/kg	0.022	0.022	
Choline	mg/kg	1200.0	1200.0	

TABLE 2 -- AAFCO Cat Food Nutrient Profiles

Nutrient	Units DM Basis	Growth and Reproduction Minimum	Adult Maintenance Minimum	Maximum
Protein	%	30.0	26.0	
Arginine	%	1.25	1.04	
Histidine	%	0.31	0.31	
Isoleucine	%	0.52	0.52	
Leucine	%	1.25	1.25	
Lysine	%	1.20	0.83	
Methionine-cystine	%	1.10	1.10	
Methionine	%	0.62	0.62	1.50
Phenylalanine-tyrosine	%	0.88	0.88	
Phenylalanine	%	0.42	0.42	
Threonine	%	0.73	0.73	
Tryptophan	%	0.25	0.16	
Valine	%	0.62	0.62	
Fat	%	9.0	9.0	
Linoleic acid	%	0.5	0.5	
Arachidonic acid	%	0.02	0.02	
Minerals				
Calcium	%	1.0	0.6	
Phosphorus	%	0.8	0.5	
Potassium	%	0.6	0.6	
Sodium	%	0.2	0.2	
Chloride	%	0.3	0.3	
Magnesium	%	0.08	0.04	
Iron	mg/kg	80.0	80.0	
Copper (extruded)	mg/kg	15.0	5.0	
Copper (canned) ^e	mg/kg	5.0	5.0	
Manganese	mg/kg	7.5	7.5	

Zinc	mg/kg	75.0	75.0	2000.0
Iodine	mg/kg	0.35	0.35	
Selenium	mg/kg	0.1	0.1	
Vitamins				
Vitamin A	IU/kg	9000.0	5000.0	750000.0
Vitamin D	IU/kg	750.0	500.0	10000.0
Vitamin E	IU/kg	30.0	30.0	
Vitamin K	mg/kg	0.1	0.1	
Thiamine	mg/kg	5.0	5.0	
Riboflavin	mg/kg	4.0	4.0	
Pantothenic acid	mg/kg	5.0	5.0	
Niacin	mg/kg	60.0	60.0	
Pyridoxine	mg/kg	4.0	4.0	
Folic Acid	mg/kg	0.8	0.8	
Biotin	mg/kg	0.07	0.07	
Vitamin B12	mg/kg	0.02	0.02	
Choline	mg/kg	2400.0	2400.0	
Taurine (extruded)	%	0.10	0.10	
Taurine (canned)	%	0.20	0.20	

APPENDIX 2

Handout of questionnaire

Project: Rendering Koi Carp and creating economic value by making pet food

About the project: Koi Carp is a pest fish that is widely spread in waterways in the Waikato region. They have a long lifespan and high fertility rates. Koi Carp are destructive on aquatic life, increase water turbidity, and decrease water quality.

Eradication methods are used to control the population, however, there are no useful methods to make good use of these captured koi carp.

This project is aiming to find out if Koi Carp is seen as acceptable by the public for pet food.

This survey is part of my Master of Engineering degree at the University of Waikato.

If you have any further questions, please feel free to contact me, Jiaoying Wei: weijiaoying@outlook.com, or my supervisor, Mark Lay: mark.lay@waikato.ac.nz, and any concerns can be raised with the chair of the research ethics committee, Karsten Zegwaard: karsten.zegwaard@waikato.ac.nz.

APPENDIX 3

Questionnaire: Pet Food and Koi Carp

1. Do you know koi carp is an invasive fish species in New Zealand?

Yes. No.

2. What do you think is a good method to handle the captured koi carp?

- Bury
- Eat by people
- Animal feed
- Plant fertilizer
- Release back
- To make other products (oil, gelatin, etc.)



3. Have you ever eaten carp?

Yes. No.

If your answer is “Yes”, to what extent can you accept the taste.

- Really cannot accept.
- Don’t taste good.
- Not too bad or good.
- Taste good.
- Really like it.

4. Do you have pets?

Yes. No.

If your answer is “No”, jump to Q6.

5. Has your pet ever eaten fish or pet food that contains fish products?

Yes. No.

If your answer is “Yes”, does your pet like the food?

Yes. No.

6. From your point of view, do you think the pet food that contains koi carp products is acceptable?

Yes. No.

7. If a new pet food product that contains carp products appears, will you buy for your pet (if you have pets)?

- Yes, I’ll have a try.
- Maybe try later if the comments are good.
- Not sure.
- Never, I cannot accept this product.

The data is collected anonymously. By submitting this form, I grant consent to this data to be used.