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CONTENT

CHAPTER 1

GENERAL INTRODUCTION

1.1. Pond farming of common carp

The pond farming of common carp (*Cyprinus carpio* L.) is of great importance in global aquaculture. Carp is cultivated in a variety of climates in ponds with various levels of management as one of the first domesticated fish (Balon, 1995). According to the FAO statistic, the production of farmed common carp in 2011 was nearly 14% (~ 3.7 million tonnes) of the total global fresh water aquaculture production (FAO, 2014). Common carp production increased during last three decades by an average global rate of 9.5% per 10 years between 1982 (449251 tonnes) and 1991. In the decade 1992–2001 production has increased to 10.4% per year. During the last decade (2002–2011) production increased slightly about 5% per year (Figure 1). The biggest producer of carp on the world is China. In 2002 China produced ~ 70% of the total global fresh water production of common carp (FAO, 2014). However also much of the production takes place in Europe ~ 145 thousand tonnes, especially in the Czech Republic, where pond farming of common carp has a 1000 year old tradition and is an integral part of the socio-cultural milieu (Edwards, 2007). The main fresh water fish species cultured in ponds in the Czech Republic is the common carp representing almost 87% out of the total fish production. This production, in a range of 20000 to 24000 tonnes per year (FAO, 2014) is achieved by utilization of a semi-intensive management which combines natural feed and additional feeding with cereals. Almost all available cereals, mostly triticale, wheat, rye, maize and barley, are currently used for supplemental feeding of carp (Hůda, 2009).

The fish ponds in Central and Eastern Europe were already being built some 900 years ago in sizes from less than a hectare to several hundred ha and they usually posess an extended earthen dam equipped with an outlet enabling complete drainage during fish harvesting. Today fish ponds and their littoral zones have become a specific type of wetland – they look like natural lakes. Almost all water bodies are either man-made fish ponds or large water reservoirs in the Czech Republic. In the 16th century, the territory of the Czech Republic (79000 km^2) had about 160000 ha of fish ponds, though only about 51000 ha now remain (Pokorny and Hauser, 2002).

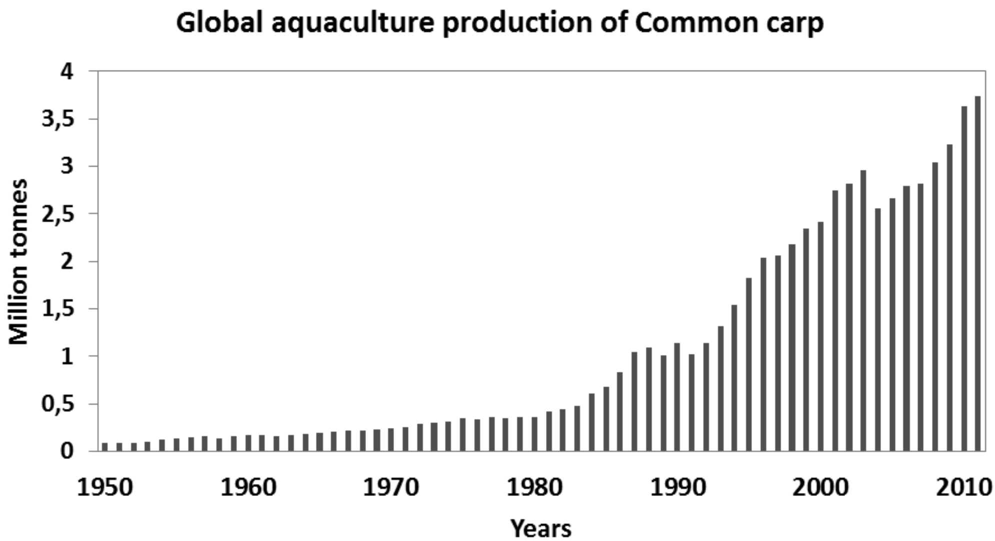

Figure 1. *Global aquaculture production of common carp over the period 1950–2011 (data adapted from FAO, 2014).*

The systematized culture techniques involve different strategies of pond management as well as fish breeding (e.g. Gela et al., 2003; Flajšhans and Hulata, 2007; Kocour et al., 2007), fry production, yearling production and marketable fish production. Relatively low-cost prepared diets are a trend and little effort has been made to compose feeds with adequate amounts of nutrients from carefully selected ingredients (Kestemont, 1995). In Central Europe, including the Czech Republic, common carp is cultured based on extensive (low stocking density, no supplemental feeding and no fertilization) and the more used semi-intensive way of farming (high density stocking, supplemental feeding, fertilization of ponds, liming, etc.). Both monoculture or polyculture with other omnivorous cyprinids (tench, roach, rudd and gudgeon, etc.) and piscivorous fish (e.g. pike, zander, etc.) are practised. In the past, also integrated systems with other animal production were used e.g. carp/duck culture in Eastern and Central Europe (Kestemont, 1995).

In general in the traditional cultural landscape with a high number of fish ponds, production is carried out in different intensifications with a high variety of fish. The yield of the ponds is usually between 100 and 1000 kg.ha^{-1} (Horváth et al., 2002) depending on the production system. In the Czech Republic fish production varies between 500 and 1000 kg.ha^{-1} (Pokorný and Hauser, 2002). In opposite, Schreckenbach (2003) describes a much lower and highly varying fish production from 15 to 670 kg.ha^{-1} for fish ponds in Germany. For fish ponds in Austria Bauer and Schlott (2009) state yields from 67 to 725 kg.ha^{-1}, Schlumberger (2002) showed that yields are seldom higher than 600 kg.ha^{-1} if only water fertilisation is applied as a pond management practice. However, the type, level, and frequency of fertilization varies from country to country. In addition to pond fertilization supplemental feeding has to be used in order to increase the fish production level (Boyd, 1982; Hepher, 1988), but the success of the fish-weight gain in the pond depends largely on climatic and typological conditions as well as good pond and feed management.

1.2. Nutrient Requirements

The dietary requirements of common carp for proteins, amino acids, lipids, fatty acids, carbohydrates, vitamins, minerals and protein-energy ratios have been investigated and summarised in several reviews (e.g. Ogino et al., 1979; Satoh, 1991; De Silva and Anderson, 1995; Kaushik, 1995; Takeuchi et al., 2002; NRC, 2011). The daily requirement of common carp for protein is about 1 g.kg^{-1} body weight for maintenance and 12 g.kg^{-1} body weight for maximal protein utilization (Ogino and Chen, 1973; Ogino, 1980b). Gatlin et al. (1986), investigated growth rates of fish fed with increasing rations from 0 to 5% of protein per body weight.day^{-1} containing either 25 or 35% crude protein from a casein-gelatin mixture. According to Takeuchi et al. (2002) the efficiency of nitrogen utilization for highest growth showed to be with a protein intake of 7 to 8 g.kg^{-1} body weight.day^{-1}. Similarly, recalculation of some data, from studies in which high growth rates were observed, showed that the protein requirements for maximal growth of common carp are 10–12 g.kg^{-1} body weight.day^{-1} (Satoh, 1991). Investigations on the optimal nutrient requirement of common carp have demonstrated that crude protein levels in the feed ranging from 30 to 38% appear to satisfy the fish. If sufficient digestible energy is contained in the diet, the optimal protein level can be effectively kept at 30–35% in the fish feed (Watanabe, 1982). De Silva and Gunasekera (1991) estimated that the dietary protein level resulting in maximal growth of major carps is 45% and that the economically optimal dietary protein content is 31%. Determination of the quantitative requirements for animo acids (AA) and essential amino acids (EAA) has been carried out, using growth response curves as well as body analyses. Studies in *Catla catla,* one of the three Indian major carps, by Ravi and Devaraj (1991) showed that the EAA needs of this species are very similar to the recommended values for common carp. Table 1 shows the requirement of AA and EAA for common carp (Nose, 1979; Ogino, 1980a; Dabrowski, 1983).

Table 1. *Amino acid requirements of common carp.*

	Nose (1979)		Ogino (1980a)	Dabrowski (1983)
Amino acid	**% in dietary protein**	**% in diet**	**% in dietary protein**	**$g.kg^{-1}.day^{-1}$**
Arginine	4.3	1.6	4.4	0.51
Cystine	5.2	2.0	0.9	N
Histidine	2.1	0.8	1.5	0.15
Isoleucine	2.5	0.9	2.3	0.26
Leucine	3.3	1.3	4.1	0.43
Lysine	5.7	2.2	5.3	0.46
Valine	3.6	1.4	2.9	0.31
Methionine	2.1	0.8	3.4	0.11
Phenylalanine	6.5	2.5	2.3	0.25
Threonine	3.9	1.5	3.4	0.21
Tryptophan	0.8	0.3	0.6	N

N, not available value.

Carp can utilize effectively both lipids and carbohydrates as energy sources, and therefore the overall digestible energy content of the diet is more important than the lipid content (Takeushi et al., 2002). It is well known that the differenceses in the digestive tract respectively the lower amylase activity in fish result in general in a lower digestibility of starch in fish than in terrestrial animals. However, carp can effectively use carbohydrates as an energy source (Ogino et al., 1976; Takeushi et al., 1979). Among fish, the amylase activity is higher in omnivorous fish, including carp, than in carnivorous fish. It has been found that common carp has a gut which is 1.5–2x longer than his body length, which is 3–4 times higher ratio of intestine to body length compared to rainbow trout. This has been suggested to be the reason for the better utilization of carbohydrates by carp (FAO, 2014). According to Takeushi et al. (2002), the optimum amount of carbohydrates in the diet can be considered to be about 30–40% for common carp.

Even marginal deficiencies in some of the minerals, trace elements or vitamins lead to severe morphological deformities in addition to poor growth of carp. The qualitative and quantitative vitamin and mineral requirements have been well investigated in some studies and a summary is provided in Table 2.

Table 2. *Available data on the mineral and vitamin requirements of common carp (Satoh, 1991; Kim et al., 1998; NRC, 2011).*

Vitamin	Requirement	**Mineral**	Requirement
Thiamine	0.5 mg.kg^{-1}	Phosphorus	6–8 g.kg^{-1}
Riboflavin	7 mg.kg^{-1}	Magnesium	0.4–0.5 g.kg^{-1}
Pyridoxine	6 mg.kg^{-1}	Iron	150 mg.kg^{-1}
Pantothenate	30 mg.kg^{-1}	Zinc	15–30 mg.kg^{-1}
Niacin	28 mg.kg^{-1}	Manganese	13 mg.kg^{-1}
Biotin	1 mg.kg^{-1}	Copper	3 mg.kg^{-1}
Choline	500 mg.kg^{-1}	Cobalt	0.1 mg.kg^{-1}
Inositol	440 mg.kg^{-1}		
Vitamin A	4000 UI		
Vitamin E	100 mg.kg^{-1}		
Vitamin C	45 mg.kg^{-1}		

1.3. Influences and Prediction of Fish Growth

Common carp is an omnivorous fish, with a high tendency towards the consumption of benthic and zooplankton organism, but carp feeds also on seeds of plants, water weeds, detritus, etc. (Tacon and De Silva, 1997). Carp is thermophilic (warmth – loving) but will tolerate extreme, long-lasting cold as well as rapid fluctuation of temperature (Horváth et al., 2002). The metabolism of carp and consequently its demand for food slows down gradually along with the decrease in temperatures, and practically stop at a water temperature of 4 °C. The optimal temperature for the growth of carp is between 23–30 °C (Kestemont, 1995; Horváth et al., 2002; Flajšhans and Hulata, 2007). The optimal pH value is 6.5–8.5, however carps show a high tolerance to variations of water ion concentration. They are also less sensitive to fluctuations in oxygen level compared to salmonids, and can be efficiently cultured even at an oxygen concentrations of 3–4 mg.l^{-1} (common carp can survive as low oxygen concentrations as 0.3–0.5 mg.l^{-1}) as well as supersaturation (Flajšhans and Hulata, 2007). Optimal oxygen saturation is between 70–75% for optimal growth of carp in ponds (Jirásek et al., 2005). Despite the potential of even minor temperature changes to alter activity in carp (Cooke and Schreer, 2003), changes in ambient water temperature exhibit a relatively mild stressor (Tanck et al., 2000). In opposite, changes in oxygen saturation have shown to generate a higher stress than water temperature changes.

In semi-intensive culture of fish pond farming the determination of variations in nutrient input and turnover from natural productivity is essential. For intensive operations, appropriate formulations and feeding practices should be adopted, considering also the potential waste discharge from metabolized or undigested feed. Typically, in semi-intensive ponds a combination of natural feed (zooplankton and zoobenthos) and supplementary feeding with an energy-rich feed, especially cereals (Edwards, 2007) is utilized. Almost all available cereals, mostly triticale, wheat, rye, maize and barley, are currently used for the feeding of carp (Hůda, 2009). Fertilization and manuring should result in an increased natural production in the ponds. According to the present proportion of zooplankton and benthos the need of supplementary cereals in is estimated subseqently. Higher yields of up to 1000 kg.ha^{-1} compared to max 400 kg.ha^{-1} in extensive systems can be obtained with additional feeding at feeding rates between 1–3% of the body weight, when the system is well managed. In common practise feed is usually supplemented three times per week (personal communication, Dr. Hůda, Třebon fisheries). Under temperate conditions, this method requires usually three or four growing seasons to produce a marketable fish of 1–1,5 kg in Western and 2–3 kg in Central Europe, and two growing seasons to obtain a 0,5–0,8 kg market fish in Eastern Europe (Kestemont, 1995).

The fish growth depends mainly on optimal temperature and age (Woynarovich et al., 2011), but also on other factors e.g. stocking density, quality and quantity of food, oxygen concentration, etc. (Horváth et al., 2002). Hence many factors are used to calculate and predict the fish growth. The best known and most useful indicators are specific growth rate (SGR) (e.g. Virk and Saxena, 2003; Urbánek et al., 2010), relative growth rate (RGR) or thermal growth coefficient (TGC). According to Jobling (2003) the TGC model is a simple and flexible model that can be used for growth prediction and production planning purposes under a variety of conditions. However, the model should not be used uncritically. For the prediction of fish growth also some more sophisticated statistical models are used. Examples are the von Bertalanffy growth model and Gompetz model, which both are compared and disussed by Yamada (2002). Moreover, Akamine (2009) presented and described useful methods for growth curve fitting, body-size composition analysis, and estimation of population size in fish stocks. These methods are statistically based on the maximum likelihood method and the likelihood ratio test. The mathematical explanation of the standard Richards growth formula with seasonal change, the generalized reproduction model, and the Awaya method for estimating implicit function models are also described by Akamine (2009). Although the concept of growth coefficients is important in growth analysis, its analytical meaning is not necessarily pointed out clearly, at least concerning commercial fish production systems.

1.4. Feed and Feed Processing

Feed used in fish farming may be classified as wet, moist or dry, depending upon the water content (Hardy, 1989; Jobling, 1994; Goddard, 1996). Wet feeds generally contain 50–70% of water, moist pellets contain 35–40% water, and dry feeds contain less than 10% of water. Wet and moist feeds are made by combining wet and dry mixes in proportions ranging from 90/10 to 50/50 (wet/dry). The bulk of the feed used in fish farming is commercially produced dry feed. Feed formulation and ingredient selection will usually be made to meet the known nutritional needs of the target species, but the choice of equipment and processing conditions used in a manufacture will have a major influence on the physical characteristic of the final feed (Thomas et al., 1997, 1998). As modern aquaculture is still a quite young business, the knowledge about feeds and processing technologies for terrestrial animals is used in the application of technologies in the production of fish feeds. A possible pre-treatment of the cereals has shown new possibilities for improvement of the production efficiency in fish production. The main aim of a pretreatment is to increase the nutritional value, taste, acceptability and especially digestibility of the fish feeds.

Pressing: is one of the less known ways to increase profitability of feed (cereals). The principle of this treatment – pressing of the cereal corn between two smooth rollers rotating against each other with the same speed – is very simple and cheap. The pressing causes disruption of the kernel surface structure and enables micro-organisms to enter into the kernel more easily, to pre-digest the kernel with enzymes better and hence enabling better utilization (Doležal et al., 2006).

Grinding: is a procedure, where individual parts of the cereal endosperm are gradually separated. The grinding process itself is divided to scrapping and seed extraction.The grinding of cereals generally improves feed digestibility, acceptability, mixing properties, pelletability, and increases also the bulk density of some ingredients. Beside this it facilitates the destruction of some of the antinutritional factors (e.g. lectins and protease inhibitors) by a subsequent suitable heat treatment, especially extrusion or expansion (Tacon and Jackson, 1985). From a nutritional point of view grinding of cereals may improve nutrient digestibility by increasing the surface area. This is known from terrestrial animals. For example McAllister et al. (1993) found that different particle fractions of grinded cereals have an influence on digestibility, especially on digestion of starch by ruminants. Smaller particles were better digestable, compared to bigger particles Also chicken and pig can better utilize fine-grinded peas which exhibited an improved digestibility of starch and protein (Daveby et al., 1998; Hess et al., 1998). On the other had there are only few studies regarding the effect of particle size on nutrient digestibility in fish, especially for omnivorous fish. However Booth et al. (2000) observed no effect of grinded diet on digestibility and weight gain of juvenile silver perch (*Bidyanus bidyanus*). Also Sveier et al. (1999) showed that particle size of fish meal had no effect on apparent protein digestibillity in Atlantic salmon (*Salmo salar*).

Mixing: Mixing of feed is commonly used for terrestrial animals as well as for fish, especially during the production of complete feeds. Dry mixers exist in two main types – vertical mixers (used in small farms) and horizontal mixers. The ratio of each compound (content of protein, lipid, carbohydrates, minerals, vitamins, etc.) is specific for each fish species and the precision of the mixingof each components leads to better utilization of the nutrients by the fish. Mixing can increase the biological and total nutrition value of feed mixtures and hence their utilization. In addition the tastiness of whole feed batches can be improved. Several factors, including the physical properities (particle size and shape, density, etc.) and mixing parameters (e.g. mixing intensity, and mixing speed and time) may influence the efficacy of the mixing (Jobling et al., 2001).

Granulation: The most modern device for a heat treatment include the so-called heat granulator. The advantage of this technology is the production of pellets with a high proportion of gelatinized starch with the preservation of high rated weight of granules (600 to 750 g/l). Contrary to the expander and extruder techniques, this is a HTMT (high-temperature-micro-time) method of treatment. The feed is exposed to high temperatures 125–170 °C for the duration of 3–4 sec. The starch becomes gelatinous during the processing; it penetrates into the structure of other feed parts, then solidifies and creates a stable structure again – a natural bonding agent. The water content of the so processed feed is around 18%. 2 to 3% of water evaporates during the passing of the feed through the pelletizing head (Doležal et al., 2006).

Expansion: The expanding technique is based on high-pressure conditioning of feed mixtures within an angular expander. The configuration of the expander is similar to that of a single-screw extruder, consisting of a thick-walled mixing tube, a heavy screw and equipment for the addition of steam. Steam is added before the feed mixture enters the expander chamber where the temperature can exceed 120 °C. The discharge valve and pressure (20–30 bar/cm^2) are adjusted hydraulically during operation depending on the desired conditioning (Jobling et al., 2001). The extruder screw applies shearing and mixing actions, and this alters the feed structure to such an extent that the binding between feed particles is enhanced. The degree of starch gelatinisation obtained by expansion can exceed 60%, the microbial content of the mixture can be significantly reduced, and there is also the possibility of adding liquid as for example oil and molasses.

Extrusion: The extruding technique was introduced into fish feed production in an attempt to increase the digestible energy content. Extrusion has all the advantages of the expansion technique. Furthermore, due to the porosity of the extruded pellet there is a possibility for an application of lipids on the surface of the feed – dressing (or coating) with oil. The processing temperature in the extruder can range between 80–200 °C, and the water content of the feed mixture can be increased to 20–30%. Thus, extrusion involves processing of ingredients at higher temperatures, moisture levels and pressures than those used in conventional steam pelleting. This can result in reduced availability of some nutrients, such as lysine, via non-enzymatic browning (Millard reaction), and increase the risk of destruction of others, such as heat-sensitive vitamins (Phillips, 1989; Camire et al., 1990; Macrae et al., 1993).

Micronising: Micronising uses the principle of irradiating the feed with infrared radiation (patent of the company *Micronizing* Co., UK) with a wave length 1.8 to 3.4 μm (Doležal et al., 2006). Retting the feed prior to radiation improves the nutritional value of the product. Short-term action of high temperatures from an infra heater enables the heating of the whole cross-section of the grains to 120–160 °C, evaporation of internal water leading to an over-pressure inside the cells and the gelatinization of the starch. The treated product can be subsequently pressed into flakes. With the input moisture of the cereals of about 15%, the moisture of the final product is approximately 10%.

Toasting: is a short-term treatment (1 to 10 minutes) with temperatures of 140 to 160 °C. There are 2 different systems existing. The rotation system type, is considered to be more efficient, because the feed is heated more equally, whereas in a belt system the most exposed areas of the cereals are easily burnt. Belt systems are suitable for treating larger or more fragile material; especially when there is a risk of larger losses due to rubbing off in a roation system (Doležal et al., 2006).

Fluid drying: The material is dried by a flow of hot air and kept moving, where the heat treatment occurs. The risk of burning and caking is nearly eliminated. The systems are suitable for the treatment of a wide range of materials. It is often used as a treatment of soy beans, food waste, etc. A disadvantage is sometimes the observation of required parameters of exposure time and medium temperature (Doležal et al., 2006).

Puffing: uses the principle of one-time release of pressure combined with the evaporation of humidity from inside of the kernel – resulting in expanding of the structure. The working space is formed by a closed cylinder, which is heated to 200 to 250 °C. The cylinder is filled with feed, heated, closed and the feed is exposed to press of 0.8–1.2 MPa. Then, the feed is immediately shot out into a reservoir. Expansion of steam during this process results in increasing of the volume of material more than ten times. The method is applicable for cereals and rice.

Although moist and wet feeds are used in some commercial fish farms the moist feed are commonly used in intensive fish farming, while the wet feeds (grains) are usually used in pond management. The last 7 described treatments of cereals or pellets are common for intensive fish farming which is based on complete diets for fish.

1.5. The impact of the carp culture system on environment

The techniques of carp culture are highly diversified, ranging from the extensive production systems in ponds or open waters with no fertilization or supplemental feeding to highly intensive systems in concrete tanks or cages (Kestemont, 1995). As all other forms of livestock production, fish production has some impacts on the environment. The current pond management (fertilization and fish feeding) together with the influences from agriculture and human settlements resulted in eutrophication of the existing ponds, so that the majority of today´s carp ponds in Central Europe can be considered as eutrophic to hypertrophic aquatic ecosystems (Všetičková et al., 2012). Some of the impacts occur due to the amount of excreted metabolites, uneaten food and/or the chemicals used during fish production (Papoutsoglou, 1992; Hlaváč et al., 2014). However, the effluents of carp culture system and its impact on environment are poorly documented compared to trout effluent of impact on the environment. Some negative impacts of pond aquaculture on the environment are also described and summarized for example by Hlaváč et al. (2014).

The problems of aquaculture related to the impact on the environment have been extensively debated (e.g. De Pauw and Joyce, 1992; Gowen, 1992; Barnabé and Kestemont, 1993). It appears that these impacts are closely related to the application of various methods and techniques which may be called „the production system". As reported previously, numerous carp production systems are used and the impact of carp culture on the environment must take the different levels of intensification into account. The intensification has significant drawbacks, such as increased environmental impact as a result of large amounts of waste discharged by effluent water (Cho and Bureau, 2001; Tacon and Forster, 2003). Intensifying fish pond systems by increasing the stocking densities, supplying large amounts of feed or excessive fertilization, etc. results in eutrophication of the ponds (Kolasa-Jamińska, 1994; Szumiec, 2002; Hlaváč et al., 2014). The main element for eutrophication of the ponds is phosphorus. Especially excess phosphorus in fish diets resulting in higher levels of excreted phosphorus is one of the main reasons causing eutrophication of the ponds (Kim et al., 1998; Jahan et al., 2003). For that reason the fish feed industry reduced phosphorus in fish feeds (Rodehutscord et al., 2000) in order to reduce the pollution of the water. Fishpond water quality is in addition affected through interactions of a range of physicochemical factors, such as temperature, oxygen regime, pH, alkalinity, transparency and nutrient content, with fish as a final link in the pond food chain (Ponce at al., 1994; Das et al., 2005; Jana and Sarkar, 2005). For example, higher temperature results in a more effective digestion offeed by the carp (Schwarz, 1997) and faster metabolism process and thus a bigger production of faeces.

During the past there also have been many changes in feed technology and feeding methods aimed to reduce the production of solid waste from uneaten or spilled feed (Bergheim and Asgard, 1996). Technological treatments such as extrusion and expansion have improved the physical characteristics (e.g. water stability, leaching characteristics, etc.) of fish feeds (Kearns, 1993; Wilson, 1994). The digestibility of ingredients and nutrient composition of the diets are among the main factors affecting the total waste output in an aquaculture production system. Therefore, beside the economical factor of loosing feed, the effort to minimize waste discharge from aquaculture should be managed through diet formulation and processing. Numerous studies have examined nutritional strategies as a way of reducing waste and minimizing the impact of waste from aquaculture on the environment. In recent years, feed quality and feeding methods have been improved to meet this goal. Economically available and suitable treatment of cereals such as mechanical or thermal treatments described above prior to the application of the feed in the ponds, can also decrease the amount of poorly or undigested feed. In general, feeding practices that minimize waste should be explored as they have a significant impact, not only on waste output but also total economy in pond farming of carp.

1.6. The impact of the carp culture system on fish flesh quality

A wide variety of factors, such as age, genetic selection, feeding strategy, fish-processing etc. have an influence on final fish flesh quality in aquaculture (Fauconneau et al., 1995). Generally, fish has a high nutritional value which is reflected in a favourable content of proteins, carbohydrates, minerals and vitamins (Özyrut et al., 2009) as well as a beneficial fatty acid composition, especially concerning the much debated polyunsaturated fatty acids (PUFA) n-3 fatty acids (Mráz et al., 2012). Regarding judging the quality of fish and fish products, consumers are particularly interested in the appearance, the taste, texture, odour and especially fat content of the product (Fauconneau et al., 1995; Rasmussen et al., 2013). Fresh fish with a fine, firm texture is highly favoured over fish with a soft texture. Texture of fish flesh or fish products can be measured in a number of ways including sensory measurements and using mechanical instruments (Coppes et al., 2002). According to Bourne and Szczesniak (2003), texture profile analysis (TPA) generates a force – time curve which is then used to quantify a number of textural parameters that correlate well with results from sensorical evaluation.

Studies dealing with sensorical quality or texture parameters of fish use different methods of sampling and a wide variety of texture analyzers to measure texture properties with different using probes (e.g. Botta, 1991; Reid and Durance, 1992; Coppes et al., 2002). On the other hand there are only few studies dealing with sensory analyses, textural parameters respectively, comparing the different culture system used in fish farming (e.g. Stejskal et al., 2011; Vácha et al., 2013).

1.7. Aims of this thesis

1) The aim of the first study was to establish a statistical model for the growth of carp during the last growing season. The sub-aim of this part was to investigate the production efficiency of different, technologically modified (pressed) cereals compared to the normal grains, respectively, usually used in common car pond practice (Chapter 2).

2) In the second study the aim was to describe the production efficiency of mechanical modified triticale (pressed and grounded) compared to untreated triticale, especially regarding the growth, feed conversion, fat content etc. for market size carp and the applicability of these treated feeds in commercial fish farming (Chapter 3).

3) The aim of the third study (Chapter 4) was to verify the efficiency of the technologically modified cereals in common practice in natural pond systems and to evaluate their impacts on pond environment. The certified technology summarizes new findings regarding the efficiency of a traditionally treated feed – cereals, which have been applied successfully in the production of carp. The technology also describes the used feeding technique and the influence of the physiological conversion process of carp feed on the balance of phosphorus, as the main indicator of pond eutrophication.

4) In the last study (Chapter 5) the aim was to explore the effect of the used production system on the sensory quality of the carp fillets. Fish from extensive and semi-intensive production system were compared regarding the textural parameters such as hardness, cohesiveness, springiness and gumminess.

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CHAPTER 2

POTENTIAL FOR IMPROVEMENT OF COMMON CARP PRODUCTION EFFICIENCY BY MECHANICAL PROCESSING OF CEREAL DIET

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Potential for Improvement of Common Carp Production Efficiency by Mechanical Processing of Cereal Diet

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Abstract

The effect of supplemental feeding with modified cereals (pressed triticale, barley, rye and pressed wheat in combination with rape) on the growth of common carp was studied under semi-intensive pond farming conditions. Non-pressed triticale, barley and rye were used for comparison. Two groups were selected as a control dependent only on natural zooplankton. For the evaluation, we employed five models designated M1 – linear mixed models with a random intercept; M2 – linear mixed models with a random slope; M3 – a linear mixed model with a random intercept and slope; M4 – written as model M3 with a power variance function, where the error variance was modelled and M5 – written as model M4 with a power variance function, with a different model of error variance. Model M5 took heterogeneous errors with respect to differing strata. Common carp that were fed supplements of modified cereals showed a significant lower variability of weight (lower SD and narrower 95% CI) compared to the non-pressed diets and pressed barley and rye that yielded higher production. These results suggest that pressed cereals increase yield in commercial production of common carp under semi-intensive conditions.

Keywords: *Cyprinus carpio*, growth models, pressed cereals, semi-intensive carp farming, variability of weight.

Introduction

Common carp (*Cyprinus carpio* L.) is the major freshwater fish species farmed in Central and Eastern Europe (Stibranyiová and Adámek, 1998; Mráz and Picková, 2009). In the Czech Republic, carp comprises 86-87% of the total fish production (Czech Ministry of Agriculture 2011) and mainly consists of semi-intensive culture in ponds (Miah *et al*., 1997; FAO 1997; Reddy *et al*., 2002; Pokorný and Hauser, 2002). The profitability of pond aquaculture is dependent on the use of economical feeds (Pigott and Tucker, 2002), and the key to efficient semi-intensive systems is the reliance on a combination of natural and artificial feed (Moore, 1985; Kaushik, 1995; Bauer and Schlott, 2006). Artificial supplements used in the Czech Republic are based almost entirely on cereal grains, an easily available economic source of energy (Turk, 1994, 1995; Mráz and Picková, 2009). Compared to pelleted feeds, cereals represent an easy and cheap source of digestible energy in form of carbohydrates, especially starch. Common carp have high activity of α-amylase and therefore efficient starch digestion; a practical benefit for pond aquaculture (Steffens, 1989). Nevertheless, cereals represent the highest cost item in common carp culture, with large quantities used in production of 2-3-year-old fish (Hůda, 2009). The availability of low cost feed plays a primary role in pond aquaculture economics (Horváth *et al*., 1992), and currently, all common cereal grain species are used for artificial feeding (Hůda, 2009).

A proper adjustment of cereals leads to an increased feed efficiency (nutritional value, acceptability and digestibility) and thus to an increase in fish growth. Contemporary fish farming aims to develop new methods of enhancing the production effectiveness of cereals by mechanical adjustment: pressing, grinding, and/or thermal treatment (Zeman, 2002; Urbánek, 2009). The way in which feed is processed affects the availability of nutrients (Tabachek, 1985; Pigott and Tucker, 2002). Current practice is crushing seeds in a cylinder press to improve digestibility. The principle is to rupture the seed coat to give access to microorganisms so that they can begin to digest the carbohydrate (Zeman, 2002). The objectives of the study were to determine the fish growth and condition in semi-intensive pond culture if pre-treated feed would improve productivity.

Materials and Methods

Study Area and Experimental Ponds

The experiment was conducted near Třeboň in the Czech Republic at 48°59'N, 14°46'E. This region is characterized as a plain basin with numerous ponds at mean altitudes of 410–450 m above sea level. The climate is temperate with the average annual temperature of 7.5°C. Annual precipitation is approximately 600–650 mm.

The experiment was conducted over 111 days from 23 May 2008 to 11 September 2008 in 9 earthen experimental ponds of the 300m^2 each with continuous water inflow. These experimental ponds had uniform characteristics in terms of size, bottom composition, wall construction, water volume, retention time and physico-chemical properties of water as they were located next to each other and had water inflow from the same pond. The ponds were filled to a depth of 1 m and had an average capacity of 300 m^3. Ponds were stocked with fish of the same age and the same genetic origin namely three-year-old Třeboň scaly common carp, of mean weight 988±31 g ind^{-1} at a density of 363 fish ha^{-1}. This density is typical for semi-intensive culture of carp in the Třeboň region.

Individual fish which was stocked into the experimental ponds were marked individually with a microchip in the dorsal musculature using a DataMars Needle Kit. During the experiment (on days 31, 53, 73 and 98) control catches were executed in each experimental pond. Fish were collected and the individual body length and individual weight were measured. After each control measurement, the fish were released back to the same experimental ponds. At the end of the experiment (day 111) individual body length and individual weight were also measured in order to assess individual growth characteristics over the entire rearing period in all experimental ponds of all fish.

Temperature and dissolved oxygen of the water inflow were monitored three times a week at 08:^{00}-10:^{00} h. Measurements used the MKT 44A INSA (oximeter INSA Company s.r.o., Prague, Czech Republic).

The zooplankton community in each experimental pond was sampled bi-weekly from the beginning of June to the beginning of September. Samples of zooplankton were taken from all ponds using a 10 L Schindler's quantitative sampler (100 µm mesh). The samples were pooled and preserved with 4% formaldehyde in polyethylene tubes. Quantitative and qualitative analyses were carried out under a stereomicroscope (Olympus BX51 binocular microscope fitted with an Olympus E-510 digital camera) in a Sedwick-Rafter chamber.

Experimental Supplemental Feeding

Seven fish groups in separate experimental ponds were fed with different supplemental cereal feeds: (i) barley, (ii) pressed barley, (iii) rye, (iv) pressed rye, (v) triticale, (vi) pressed triticale, and (vii) pressed wheat and rape (50%/50%). Two additional groups provided only with naturally available food served as controls. The chemical analysis of the feed showed that the differences among the cereals in digestible energy (DE), protein content and carbohydrates were minimal (Table 1). The pressed form of barley, rye, triticale, wheat, and rape was made using a pressing cylinder (type KB 160/2) to obtain the final particle size of 1.3 mm with the aim of eliminating the losses caused by floating.

Feeding Management

The cereals were placed three times a week by hand (Monday, Wednesday and Friday) on the feeding pits (concrete panel) at 08:^{00}-09:^{00} h at an initial rate of 5% of fish stock biomass. Feeding pits consist of a concrete place on the bottom of each experimental pond. There it is easy to check if and how much feed is consumed by the fish.

Formulae for Growth, Feed Conversion and Feed Retention and Condition

Standard formulae were used to assess growth, feed utilization and other relevant parameters during the feeding trial. The Specific Growth Rate was estimated according to Virk and Saxena (2003). The Feed Conversion Ratio [FCR] was calculated as described by Steffens (1989) and the Fulton coefficient [FC] was estimated according to Arlinghaus and Hallermann (2007)

Table 1. Chemical analysis and Digestible energy (DE) in cereals used in the experiment

	Dry matter	Protein	Fat	Starch	DE [a]		
	(g.kg^{-1})	(g.kg^{-1})	(g.kg^{-1})	(g.kg^{-1})	(MJ.kg^{-1})	(MJ.ind.$^{-1}$)	(MJ.ind^{-1}.day^{-1})
Barley	870	110	21	676	12.489	31.78	0.286
Pressed barley	870	110	21	676	12.489	31.78	0.286
Rye	870	85.6	13.8	721	12.499	31.81	0.286
Pressed rye	870	85.6	13.8	721	12.499	31.81	0.286
Triticale	880	106	19	715	12.928	31.73	0.285
Pressed triticale	880	106	19	715	12.928	31.73	0.285
Pressed wheat and rape	876	180	360	90	14.211[b]	28.42	0.255

[a] Digestible energy; [b] value obtained as weighted average of values for wheat (60%) and rape (40 %).

Statistical Analysis and Growth Models

One-way ANOVA with fixed effects was used to test the hypothesis of equal mean weight of stocked fish in all groups. Homogeneity of variance was tested through Bartlett's test (Bartlett, 1937). For planned variance comparisons we used classical two samples *F*-test (Mason *et al*., 2003). Confidence intervals for standard deviation based on normal asymptotic theory are also provided.

Due to the fact that we were primarily interested in the fourth growing season, which is crucial for final production, we used linear models to describe the growth data. The growth trajectory could be roughly characterized as increasing at a constant rate during the experimental period, which could be satisfactorily described through the linear model. To fit linear growth models, we used several linear mixed models that could be expressed in matrix form $y_i = X_i\beta + Z_i b_i + \varepsilon_i$ (Laird and Ware 1982). We assume the vector of random effect to be $b_i \sim N(0,\Psi)$ and within-group error $\varepsilon_i \sim N(0,\sigma^2\Lambda_i)$.

We employed five models designated M1 – a linear mixed model with a random intercept; M2 – a linear mixed model with a random slope; M3 – a linear mixed model with a random intercept and slope; M4 – written as model M3 with a power variance function, where the error variance was modelled as $Var(\varepsilon_{ij}) = \sigma^2 |t_{ij}|^{2\delta_{ij}}$ and with one covariate function $g(t_{ij},\delta_{ij}) = |t_{ij}|^{\delta_{ij}}$; and M5 – written as model M4 with a power variance function, with the error variance modelled as $Var(\varepsilon_{ij}) = \sigma^2 |t_{ij}|^{2\delta_{s\,ij}}$ and one covariate function $g(t_{ij},\delta_{ij}) = |t_{ij}|^{\delta_{s\,ij}}$. The later model takes heterogeneous errors with respect to differing strata, e.g. different diet, into account.

Model Selection and Hypothesis Testing

For fitting the linear mixed-effect model we used the maximum likelihood (ML) details of the applied algorithm, provided, for example, by Pinheiro and Bates (2000). This method enables the use of Information Theory for model selection. For this purpose we used Akaike information criterion, *AIC* = -2log(θ |X)+2*k*, which approximates the Kullback-Leibler distance (Burnham and Anderson, 2002) and the Bayesian information criterion (BIC). In this formula, log(θ |X) calculates the numerical value of the log-likelihood function evaluated at its maximum for a particular model. The vector θ contains the estimated parameters of the evaluated model and *k* is the number of estimated parameters. For more details on this topic see Akaike (1974). The model with the smallest *AIC* value was selected as the most suitable model among the tested models.

Software

The numerical evaluation was carried out with the programming environment R 2.8.1 (R development core team, 2008). For the estimation of the parameters in linear mixed models we used the library name written by Pinheiro *et al*. (2008).

Results

Growth Models and Analysis with Respect to Diet

The hypothesis of homogeneity of the experimental fish groups with respect to their weight at the beginning of the experiment was tested through one-way analysis of variance with result *F* = 1.540 e.g. *p* = 0.160. Therefore, we can conclude that all groups were, on average, of similar weight at the start of the experiment. The hypothesis of equal variance in all groups at the start of the experiment was confirmed by Bartlett's test with results χ^2 = 2.416 e.g. *p* = 0.933.

We provide Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) for each of the fitted models, and also compare the models by the likelihood ratio test. A larger *p*-value for the likelihood ratio and smaller AIC and BIC values for the considered model indicate that it should be preferred (P<0.0001). Model M3 is better than model M2 due to smaller AIC and BIC values (Table 2). The preferred model is model M5 with AIC = 7578 and BIC 7702. This model has the following form

$$y_{ij} = (\beta_0 + \gamma_{02}D_{2i} + \gamma_{03}D_{3i} + \gamma_{04}D_{4i} + \gamma_{05}D_{5i} + \gamma_{06}D_{6i} + \gamma_{07}D_{7i} + \gamma_{08}D_{8i} + b_{0i}) + (\beta_1 + \gamma_{12}D_{2i} + \gamma_{13}D_{3i} + \gamma_{14}D_{4i} + \gamma_{15}D_{5i} + \gamma_{16}D_{6i} + \gamma_{17}D_{7i} + \gamma_{18}D_{8i} + b_{1i}) \cdot t_{ij} + \varepsilon_{ij}, \quad \text{(M5)}$$

where D_{2i} is the binary variable taking the value 1 if the *i*-th fish receive barley and 0 otherwise. The coefficient D_{3i} is a binary indicator variable for the pressed form of barley, D_{4i} is a binary indicator for rye and so on (Table 3). The coefficient β_0 and β_1 are, respectively, the average intercept and average slope for fish under natural diet (control groups).

In such parameterization the coefficient γ_{0k} could be interpreted as an average difference in intercept between fish under the natural feeding regime and fish receiving a *k*-th specific diet, e.g. fish consuming barley, fish fed pressed barley, rye, and so on. Values of the estimated fixed parameters for the model M5 are shown with standard errors and significance test in Table 3. There is a significant

Table 2. Summary statistics for the fitted models

Model	AIC	BIC	log(θ |X)	Test	Likelihood ratio	P-value
M1	7973	8053	-3969			
M2	7710	7789	-3837			
M3	7669	7758	-3815	M2 vs. M3	44.31	< 0.0001
M4	7646	7739	-3802	M3 vs. M4	25.33	< 0.0001
M5	7578	7702	-3761	M4 vs. M5	81.96	< 0.0001

Table 3. Parameter estimates and associated statistic for fixed effects in the linear mixed model M5

Effect	Parameter	Estimate	Standard error	*t*-value	P-value
Control	β_0	1058.80	24.67	42.92	< 0.00001
Day (t_{ij})	β_1	6.30	0.53	11.91	< 0.00001
Barley	γ_{02}	-11.00	46.14	-0.24	0.8117
Pressed barley	γ_{03}	-58.10	45.99	-1.26	0.2093
Rye	γ_{04}	58.00	46.06	1.26	0.2113
Pressed rye	γ_{05}	-3.60	44.16	-0.08	0.9350
Triticale	γ_{06}	-109.70	50.76	-2.16	0.0333
Pressed triticale	γ_{07}	-44.30	44.01	-1.01	0.3169
Wheat and rape	γ_{08}	57.10	41.16	1.39	0.1690
Barley $\times\ t_{ij}$	γ_{12}	2.70	0.95	2.83	0.0048
Pressed barley $\times\ t_{ij}$	γ_{13}	3.70	0.95	3.86	0.0001
Rye $\times\ t_{ij}$	γ_{14}	4.10	0.95	4.33	< 0.00001
Pressed rye $\times\ t_{ij}$	γ_{15}	4.20	0.93	4.46	< 0.00001
Triticale $\times\ t_{ij}$	γ_{16}	4.50	1.03	4.35	< 0.00001
Pressed triticale $\times\ t_{ij}$	γ_{17}	4.30	0.93	4.59	< 0.00001
Wheat and rape $\times\ t_{ij}$	γ_{18}	1.60	0.90	1.73	0.0839

interaction of barley, pressed barley, rye, pressed rye, triticale, and pressed triticale with time (Table 3).

Both forms of triticale and rye have the highest value of the linear regression coefficient, indicating that these cereals are more efficient than the others. Detailed analysis of the weight variability is shown below in Table 5. Random components b_{0i} and b_{1i} in each model shown in Table 4 are assumed to be the result of bivariate normal distribution $\mathrm{N}(0,\Psi)$ where $\boldsymbol{0} = (0,0)^T$ and Ψ is variance-covariance matrix estimated as $\hat{\Psi} = \begin{bmatrix} 98.298 & 0.144 \\ 0.144 & 2.371 \end{bmatrix}$. We provide a predicted growth trajectory for all combinations of experimental fish groups. Pressed feeds produced lower variability and higher daily weight gain than the non-pressed cereals (Figure 1). Only the pressed form of triticale showed a lower average value of daily weight gain than whole triticale (Table 5).

Individual Fish Weight

At the end of the experiment (111 days), common carp on diets supplemented with intact rye and those fed pressed rye reached the highest individual weight at 2225±330 g.ind^{-1} and 2190±264 g.ind^{-1}, respectively. The third highest weight 2145±296 g ind^{-1} was obtained with pressed triticale. Common carp fed a diet supplement of intact non-pressed triticale reached the final weight of 2128±554 g ind^{-1}. A lower final weight of 2049±250 g ind^{-1} was found for common carp fed pressed barley and 1993±299 g ind^{-1} for those fed with non-pressed barley. The group fed pressed wheat and rape had final individual weight 1940±296 g ind^{-1}. The lowest final weight was found for carp in the control groups at 1732±281 g ind^{-1} (Table 5).

Significant differences (P<0.05) were observed in standard deviation (SD) values during the course of the experiment (Table 5). At the end of the experiment, the highest SD values were found for supplemental feeding without adjustment: triticale, SD 554 g ind^{-1}; rye, SD 330 g ind^{-1}; and barley, SD 299 g ind^{-1}. The average SD value of fish weight in fish fed the non-pressed variants reached 394 ind^{-1} at the end of the experiment. All fish fed pressed cereals

Table 4. Regression models for particular diet based on the mixed model M5

Diet	Fitted model	Variance of ε_{ij}
Control	$1058.8 + b_{0i} + 6.3 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.18349}$
Barley	$1047.8 + b_{0i} + 9.0 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.08062}$
Pressed barley	$1000.7 + b_{0i} + 10.0 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.0857}$
Rye	$1116.8 + b_{0i} + 10.4 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.0834}$
Pressed rye	$1055.2 + b_{0i} + 10.5 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.15207}$
Triticale	$919.1 + b_{0i} + 10.8 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{2 \cdot 0.10039}$
Pressed triticale	$1014.5 + b_{0i} + 10.6 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.15787}$
Wheat & rape	$1115.9 + b_{0i} + 7.9 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \lvert t_{ij} \rvert^{-2 \cdot 0.20465}$

Table 5. Point estimate (mean ± SD) of the weight (g) and 95 % confidence interval for standard deviations of the weight with respect to the different diets and time from stocking in grams

Day from stocking	Form of feed	(c) Control (*n*=22)	(b) Barley (*n*=11)	(r) Rye (*n*=11)	(t) Triticale (n=11)	(w) Wheat & rape (n=12)
1	Non-pressed	951 ± 104 (82.4-150.8)	976 ± 99 (72.8-182.8)	1050 ± 82 (60.7-152.4)	947 ± 121 (88.9-223.3)	Not tested
	Pressed		1002 ± 88 (65.0-163.3)	997 ± 85 (62.4-156.6)	988 ± 92 (67.6-169.9)	956 ± 89 (66.5-159.4)
31	Non-pressed	$1275 \pm 172_{r}$ (136.3-249.3)	$1360 \pm 204_{r}$ (149.8-376.2)	$1469 \pm 172_{r}$ (126.3-317.3)	$1327 \pm 217_{br}$ (159.3-400.1)	Not tested
	Pressed		1279 ± 124 (91.46-229.71)	1412 ± 84 (61.7-155.0)	$1330 \pm 166_{r}$ (121.9-306.3)	$1375 \pm 163_{r}$ (120.9-289.7)
53	Non-pressed	1421 ± 176 (139.3-254.8)	1582 ± 192 (141.1-354.5)	1730 ± 225 (165.2-414.9)	$1534 \pm 257^{c}_{br}$ (188.3-473.0)	Not tested
	Pressed		1582 ± 142 (104.2-261.7)	1635 ± 148 (108.5-272.6)	1603 ± 170 (125.2-314.4)	1566 ± 200 (146.6-368.1)
73	Non-pressed	1506 ± 223 (176.4-322.9)	1651 ± 204 (149.5-375.5)	1822 ± 236 (173.3-435.3)	$1680 \pm 342^{cb}_{brt}$ (251.3-631.1)	Not tested
	Pressed		1690 ± 151 (111.3-279.6)	1763 ± 167 (122.7-308.1)	1774 ± 198 (145.1-364.4)	1686 ± 225 (166.8-399.7)
98	Non-pressed	1694 ± 266 (210.7-385.5)	1987 ± 274^{t} (201.5-506.0)	2190 ± 330 (242.4-608.9)	$2045 \pm 503^{cb}_{brtw}$ (368.7-926.0)	Not tested
	Pressed		2052 ± 234 (171.5-430.7)	2126 ± 234 (171.6-430.9)	2096 ± 267 (195.8-491.8)	1923 ± 287 (212.4-509.1)
111	Non-pressed	1732 ± 281 (222.2-406.7)	1993 ± 299 (219.3-550.9)	2225 ± 330 (242.1-608.1)	$2128 \pm 554^{cb}{}_{b}{}^{r}{}_{rtw}$ (406.2-1020.2)	Not tested
	Pressed		2049 ± 250 (183.4-460.7)	2190 ± 264 (193.8-486.7)	2145 ± 296 (217.1-545.4)	1940 ± 296 (219.2-525.5)

Alphabetical subscripts are used to indicate significant differences among different diets (P-value<0,05; *F*-test to compare two variances). Alphabetical superscripts are used to indicate significant difference between non-pressed and pressed form of particular feed (P-value<0,05; *F*-test to compare two variances).

showed significantly lower SD values (P<0.05): pressed barley, SD 250 g ind^{-1}; pressed rye, SD 264 g ind^{-1}; and pressed triticale SD 296 g ind^{-1}. The average SD value for fish fed pressed variants was 270 g ind^{-1} at the end of the experiment.

Weight Gain, Feed Utilization and Condition Factor

Differences among the cereals in digestible energy (DE) and content of proteins and carbohydrates were minimal (Table 1). Common carp fed pressed rye showed the greatest individual weight gain, 1.192 kg ind^{-1}, with FCR of 2.13 and SGR of 0.7 (Table 6). The non-pressed triticale group showed individual weight gain of 1.180 kg ind^{-1} with FCR of 2.08 and SGR of 0.72. Common carp fed non-pressed rye showed individual weight gain of 1.175 kg ind^{-1} with FCR of 2.17 and SGR of 0.67. Intermediate individual weight gain 1.156 kg ind^{-1} was reached by

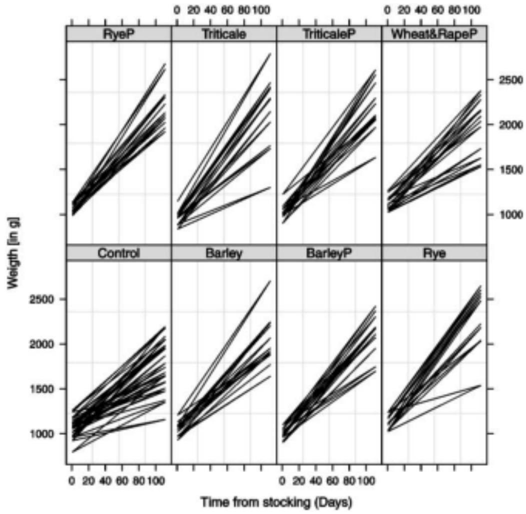

Figure 1. Predicted growth trajectory based on the linear mixed effect model M5.

common carp fed with pressed triticale with FCR 2.13 and with SGR of 0.69.

At stocking in May, the mean FC for carp was 3.07±0.12. During the growing season, FC values slowly increased with increasing fish weight. However, in August (at 73 days), a decrease of FC values in the all groups of fish was observed. At harvest (111 days), the highest FC value was seen in the non-pressed triticale group at 3.36±0.27 and the non-pressed barley group at 3.35±0.23. The group fed pressed wheat and rape reached similar FC values at 3.23±0.27. The pressed barley had FC 3.19±0.49, and the control carp had FC 3.19±0.24. The lowest FC value at the end of the experiment, 3.13±0.23, was found in the group receiving pressed rye.

Environmental Parameters and Zooplankton

The mean value of the temperature and dissolved oxygen were 20.7±1.7°C and 6.07±1.19 mg L^{-1}, respectively. The lowest values of temperature were observed during the September. Both parameters showed no significant difference among the experimental ponds ($P>0.05$). Mean abundance of zooplankton was 135±87 ind L^{-1}. Cladocerans (especially *Bosmina longirostris*) were dominant throughout the experiment (94%). Copepods, represented mainly by *Thermocyclops crassus*, comprised 4% of the zooplankton community. Rotifers represented 2%. No significant differences were noted in zooplankton density among the experimental ponds.

Discussion

The common carp is omnivorous with wide food plasticity (Urán *et al*., 2008). At the beginning of the growing season, it filters zooplankton and consumes carbohydrates to fulfil its energy needs, using exogenous enzymes obtained from zooplankton (e.g. cladocerans) for digestion of carbohydrates. Skeletons of cladocerans and copepods aid in the mechanical digestion of food (Jancarik, 1964; Strumbauer and Hofer, 1986).

According to Shimeno *et al*. (1997), in summer a decrease in the activity of glycolytic and lipogenic enzymes occurs, and carp become almost totally herbivorous. In order to digest carbohydrates, endogenous enzymatic activity was found to gradually increase (Shimeno and Shikata, 1993a, b). Hartman (2005) found that unconsumed feed particles appeared on the pond water surface in this period. Their nutritional intake was limited to the necessary essential ration, and only after the ability of the carp to utilize carbohydrates had developed, they started to take up dietary amounts adequate for their growth. This adverse transient period can be shortened by providing pressed cereals, which are more digestible than whole seeds.

In the present study, growth of common carp in the rearing ponds was characterized by two seasonal maxima with the greatest weight increase in June and August. Between the two growth peaks, a reduction in the rate of weight gain was observed, which can be explained both by decreasing quantity of natural food and the gradual adaptation of fish to supplemental feed. It is known, that a reduction in the activity of digestive enzymes at low water temperatures of diet could also be responsible for the decrease in apparent digestibility with the decrease in water temperature. Variations in water temperature have a great effect on fish basal metabolism, because fish are poikilotherms and their metabolic rate is determined by the environmental temperature. A decrease in weight gain

Table 6. Main management and production data (non-pressed and pressed cereals)

	Rye	Pressed Rye	Triticale	Pressed Triticale	Barley	Pressed Barley	Pressed wheat and Rape	Control
Experimental pond area (m^2)	300	300	300	300	300	300	330	300
Stocked ($ind.ha^{-1}$)	363	363	363	363	363	363	363	363
Stocked (ind.)	11	11	11	11	11	11	12	11
Initial total weight (kg)	11.56	10.97	10.42	10.87	10.75	11.03	11.48	10.94
Initial individual weight ($kg.ind.^{-1}$)	1.05	0.99	0.95	0.99	0.98	1.00	0.96	0.95
Harvest (ind.)	11	11	11	11	11	11	12	22
Final total weight (kg)	24.48	24.08	23.41	23.59	21.92	22.53	23.27	19.91
Final individual weight ($kg.ind^{-1}$)	2.23	2.18	2.13	2.14	1.99	2.05	1.94	1.73
Total weight gain (kg)	12.93	13.12	12.99	12.72	11.17	11.51	11.79	8.98
Individual weight gain ($kg.ind.^{-1}$)	1.18	1.19	1.18	1.15	1.01	1.05	0.98	0.78
Total cereal consumption (kg)	28.04	27.93	27.01	27.09	27.93	27.95	24.06	-
FCR	2.17	2.13	2.08	2.13	2.50	2.43	2.04	-
SGR	0.67	0.7	0.72	0.69	0.64	0.64	0.63	0.54
FCR/SGR	3.24	3.04	2.89	3.09	3.91	3.8	3.24	-

in September could be a combined effect influenced by less efficient digestion, basal metabolism associated with worsening environmental conditions caused by decreasing temperature.

According to Dumas *et al*. (2010) fish weight gain is highly dependent on water temperature. The temperature of most fish species are linked to that of the environment. The digestive system of fish is effectively adapted ambient temperature and the temperature has an influence on fish metabolism. Horn (1998) stated that temperature limits the microbial fermentation in the gut of common carp. Schwarz (1997) reported that common carp digestion is most effective at 23-25°C. When the water temperature decreases from 25 to 18°C, digestion in common carp is significantly reduced (Kim *et al*., 1998; Yamamoto *et al*., 2001, 2007; Clements and Raubenheimer, 2006). Water quality parameters (temperature and oxygen) measured during the experimental period corresponded to common values recorded in Czech ponds and remained within the ranges necessary for good growth performance of carp (Billard, 1999). Both parameters showed no significant difference among the experimental ponds ($P>0.05$), indicating that feeding experiments had not been biased by water parameters.

Daily weight gain of common carp fed pressed rye was 1.45% higher, and the conversion of feed 1.85% lower, than in common carp fed non-pressed rye. The results for barley may have been influenced by higher fibre content (5.40%), which reduces the digestibility of other components (Jirásek, 2005). According to Pigott and Tucker (2002) digestion is the most important factor limiting nutrient availability. When altering grains by pressing, digestibility increases as indigestible constituents are crushed and fibre is split. In the pressed barley group, daily weight gain was 2.88% higher and the feed conversion was 2.80% lower than in the non-pressed barley group. Common carp receiving pressed wheat and rape showed low growth rate. Jackson *et al*. (1982) found that a high proportion of rape in feed is associated with growth depression in omnivorous fish and α-amylase inhibitors in wheat appear to reduce starch digestibility (Storebakken *et al*., 2000). The results for the combination of wheat and rape in the present study confirm this. Higher efficiency of pressed cereals was not shown for triticale. Daily weight gain for the non-pressed triticale group was 2.07% higher, and the conversion was 2.35% lower, than in the pressed triticale group. This result could have been influenced by high variation in fish weight or by the degree of pressing of the triticale, which may have led to higher losses of feed due to its dispersion in the water.

Przybyl and Mazurkiewicz (2004) showed that triticale, wheat and rye had a similar feed conversion factor, when used in extruded feeds. The higher FCR for pressed triticale compared to non-pressed grains in our study could be due to the processing methods. When pressing seeds the hull is crushed and the starch gets in contact with the water. We hypothesize that due to the different starch characteristics and higher amount of small starch granules in triticale compared to for example barley, wheat and rye (Ao and Jane, 2007; Gassner *et al*., 1989) starch from triticale is leaking to the water to a higher degree than from the other cereals. However this needs to be confirmed in another study.

Conclusion

Our results indicate that the production efficiency of cultured common carp can be increased by the supplementation of pressed rye or barley instead of non-pressed cereals. Feeding pressed rye or barley resulted in similar or higher weight gain at lower FCR values, and hence a decrease of feeding costs. In addition common carp fed pressed cereals showed lower variation in weight in comparison with those fed non-pressed cereals. As homogeneous size and weight minimizes manipulation during sorting and hence reduces stress, this finding will positively affect common carp welfare during harvesting. In order to optimise the feeding efficiency, the increased production efficiency of pressed rye and barley needs to be further investigated and verified. There is also a need to investigate why pressed triticale was less effective.

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CHAPTER 3

USE OF MODIFIED CEREALS AND THEIR EFFECT ON GROWTH, FEED CONVERSION, FAT CONTENT, AND FILLET YIELD OF MARKET SIZE COMMON CARP GROWN IN PONDS

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USE OF MODIFIED CEREALS AND THEIR EFFECT ON GROWTH, FEED CONVERSION, FAT CONTENT, AND FILLET YIELD OF MARKET SIZE COMMON CARP GROWN IN PONDS

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Abstract

Effect of supplemental feeding with unmodified and modified triticale on the growth, feed conversion, fat content, and fillet yield of 3-year-old Třeboň scaly carp was studied under semi-intensive pond farming conditions (Czech Republic, Central Europe). The trial was conducted in 83-day-experiment in duplicate experimental ponds. Fish fed pressed or ground triticale reached significantly ($P < 0.05$) higher mean individual weight gain (IWG 1.00 and 0.95 kg ind^{-1}, respectively) and specific growth rate (SGR 0.70 and 0.68% d^{-1}, respectively) than that of carp fed unmodified triticale (IWG 0.86 kg ind^{-1} and SGR 0.61% d^{-1}). The fat content was highest in fish fed pressed triticale but did not significantly differ from fish fed ground or whole grain triticale. Processed filet yield with skin did not significantly differ between groups fed modified and unmodified triticale (44.33 and 44.78%, respectively). We found moderate positive correlation (Spearman's ρ test; $\rho = 0.59$) between fillet yield and weight but no correlation between ($\rho = 0.30$) fillet yield and standard body length. Significantly ($P < 0.05$) lower mean values of IWG (0.65 kg ind^{-1}), SGR (0.49% d^{-1}), fat content (4.6%), and fillet yield (41.9%) were observed in a group of fish dependent only on natural zooplankton. Common carp is able to better utilize pressed and ground triticale compared to unprocessed triticale, which was indicated by the decreased FCR of 14.1% and 9.5%, respectively. This results in decreased feeding costs in commercial production of common carp under semi-intensive conditions.

Keywords: *Fulton's condition factor, grinding, pressing, semi-intensive production, triticale, zooplankton*

Introduction

Common carp (*Cyprinus carpio* L.) is among the most widely cultured species of freshwater fish, with a total global production of ~ 3.2 million tonnes in 2010 (FAO, 2012). Much of the production takes place in Central Europe, especially in the Czech Republic where pond farming of common carp is a 1000 year old tradition and an integral part of the socio-cultural milieu (Edwards, 2007). Common carp is the best choice for commercial utilization of pond resources in the temperate climate of Central and Eastern Europe (Woynarovich et al., 2011).

In Central Europe, including the Czech Republic, common carp is cultured in supplementary feeding-based extensive or semi-intensive ponds, considered to be an environmentally sound animal protein production (FAO, 2006–2013). Typically, the semi-intensive ponds utilize a combination of natural food and supplementary feeding with energy-rich cereal grains such as barley, maize, rye, triticale, and wheat (Edwards, 2007). Such cereals contain high proportions of carbohydrate and often make up 35–45% of the total diet (Przybyl and Mazurkiewicz, 2004).

Common carp can utilize large amounts of carbohydrates due to high levels of amylase and maltase activity (Urbánek et al., 2010). However, the utilization of raw starches, which form the major constituent of cereal grains, can vary from 60 to 99% depending on the characteristics of the cereal (Hernández et al., 1994; Medale et al., 1999; Krogdahl et al., 2005). Higher digestibility can be obtained by subjecting cereals to pre-treatment, especially thermal-based such as roasting, cooking, and expanding (Przybyl and Mazurkiewicz, 2004). However, such treatments are expensive and economically unfeasible in pond culture of common carp, which is currently experiencing static production and a negative market image (FAO, 2006–2013).

A further problem associated with use of carbohydrate-rich feed for common carp is excess fat deposition (Yamamoto et al., 2003), which affects its sensory qualities (Oberle et al., 1997) and, consequently, marketability and consumption. The acceptance of low fat as linked to human health means that fat content will continue to be an important parameter affecting the acceptability of common carp flesh (Bauer and Schlott, 2009). In Germany and Austria, programs have been initiated to improve the quality of common carp, especially a reduction of fat content (Oberle, 2008; Bauer and Schlott, 2009).

Common carp has an outstanding significance in freshwater aquaculture and will remain an important species in those areas where it has been traditionally farmed. Research will need to focus on, among other things, improved rearing techniques, product quality control, product diversification, and marketing (FAO, 2004–2013). The objectives of the study were to determine the growth, condition, feed conversion, fat content, and fillet yield of common carp in semi-intensive pond culture fed supplements of economically sustainable pressed and ground cereals.

Material and methods

Study area and experimental ponds

The experiment was carried out from June 30 to September 20 2010 in Třeboň, Czech Republic in eight experimental ponds with depth of 1 m and an area of 309.6 ± 6.4 m^2 each. The fish were divided into four groups in duplicate ponds (triticale, grinded triticale and pressed triticale). Fish in two of the ponds were served as controls, kept only on natural zooplankton. The ponds were stocked with three-year-old Třeboň scaly common carp, mean weight 1271 ± 145 g at a density of 363 $fish.ha^{-1}$.

Feeds and feeding

Experimental treatments consisted of triticale fed as pressed, ground, or with no modification. Pressed cereals were prepared using the Himel GQ 43 (Germany), distance between a rollers 1.3 mm. Grinding used a roller grinding mill (Bühler DZFL 1500 Switzerland), particle size triticale 1.3 mm).

Fish were fed supplements three times a week (Monday, Wednesday, Friday) with the cereal placed in a concrete feeding pit from 8:00 to 9:00 at an initial rate of 2% of fish biomass. Feeding rate was adjusted during the rearing period based on food intake and increase in fish stock biomass, adjusted according to the presence of large cladocerans and according to the common carp weight. This way of supplemental feeding is frequently used in pond aquaculture in the region (Fig. 1). The major objective was to regulate the amount of feed to achieve an amount providing uniform energy level across all experimental groups, relative to the individual fish in the experimental ponds.

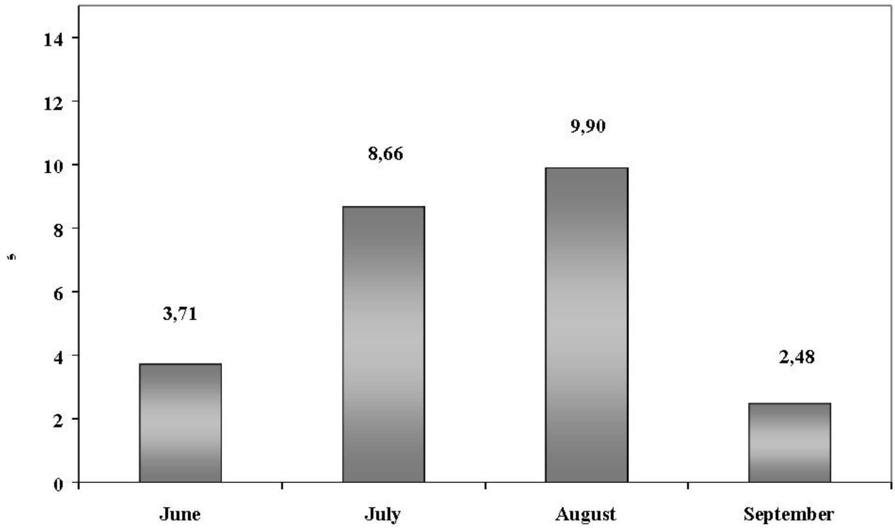

Figure 1. *Feeding rations during the growing season (kg per experimetal pond).*

Pond water quality and zooplankton

Pond water quality was measured using YSI Professional Plus (6050000, YSI Incorporated, Yellow Springs, USA). Water temperature (°C) and dissolved oxygen (mg.L^{-1}) were monitored 3 times weekly from 08:00 to 08:30, and were 21.0 ± 2.7 °C and 6.2 ± 1.6 mg.L^{-1}, respectively. The pH was 7.1 ± 0.4.

The zooplankton community in each experimental pond was sampled bi-weekly from the beginning of July to the beginning of September. Samples of zooplankton were taken from all ponds using a 10 L Schindler's quantitative sampler (200 μm mesh). The samples were pooled and preserved with 4% formaldehyde in polyethylene tubes. Quantitative and qualitative analyses were carried out under a stereomicroscope (Olympus BX51 binocular microscope fitted with an Olympus E-510 digital camera) in a Sedwick-Rafter chamber. Mean abundance of zooplankton was 204 ± 127 ind.L^{-1}. Cladocerans (especially *Bosmina longirostris*) were dominant throughout the experiment (83%). Copepods, represented mainly by *Thermocyclops crassus*, comprised 13% of the zooplankton community. Rotifers represented 4%.

Chemical analyses of feeds

Composition of the cereals was determined following standard methods (AOAC, 1984): dry matter was calculated by drying at 105 °C to constant weight; crude protein (N x 6.25) by the Kjeldahl method after acid digestion; crude lipid by petrol ether extraction in a Soxtec System HT; ash by combustion in muffle furnace at 550 °C for 12 h; gross energy by micro-bomb calorimeter (Tab. 1).

Table 1. *Supplementary diet composition.*

Supplement source	Dry matter [g kg^{-1}]	Protein [g]	Fat [g]	Carbohydrate [g]
Triticale pressed	869	89	15	649
Triticale ground	865	86	16	651
Triticale (whole grain)	863	87	14	655

Parameters analyzed and calculations.

Digestible energy (DE) in cereals was calculated according to Steffens (1989) (Table 2).

DE = 0.0168 * protein + 0.0335 * fat + 0.0147 * carbohydrate

Table 2. *Digestible energy (DE) in cereals used as supplementary diet for carp.*

Digestible energy Food source	Triticale pressed	Triticale ground	Triticale (whole grain)
Protein DE [MJ kg^{-1}]	1.50	1.45	1.46
Fat DE [MJ kg^{-1}]	0.50	0.54	0.47
Carbohydrate [MJ kg^{-1}]	9.54	9.57	9.63
Total DE [MJ kg^{-1}]	11.54	11.55	11.60
Total cereal consumption [kg]	24.75	24.75	24.75
Total DE [MJ]	285.57	285.88	286.10
DE [MJ per carp]	25.96	25.99	26.01

Survival rate, Fulton's condition factor (FC), fish weight gain, feed conversion ratio, and specific growth rate, were calculated as follows:

Survival rate [SR %] = 100 x final fish number/initial fish number.

Fulton's condition factor

$$FC = \frac{m}{BL^3} * 100$$

where m is the body weight [g] and BL is the body length [cm].

Feed Conversion Ratio [FCR]

$$FCR = \frac{F}{(w_t - w_o)}$$

where w_t is the final body weight [kg], w_o is the initial body weight [kg], and F is the feed consumed [kg].

Specific Growth Rate [SGR (% d^{-1})]

$$SGR = \frac{\ln w_t - \ln w_o}{t^{-1}} * 100$$

Estimation of percent fillet with skin

Filleting of fish at the end of the trial was conducted by one person to ensure consistency. The trimmed fillets were immediately weighed, and the yield was calculated as percent of body weight according to the following formula:

Percent fillet with skin [%] = 100 * weight fillet/final body weight

Estimate of fat content

The fat content of the fish was determined using a portable Fish Fat meter Kit FM 692 Distell (Distell, Faldhouse, West Lothian, Scotland) with modifications (Fig. 2). The Fish Fatmeter is response to measure lipid content of fish simply, and non-destructively. The accurancy of the Fatmeter ranges from an uncertainly in the fat content ± 1% (95% confidence interval).

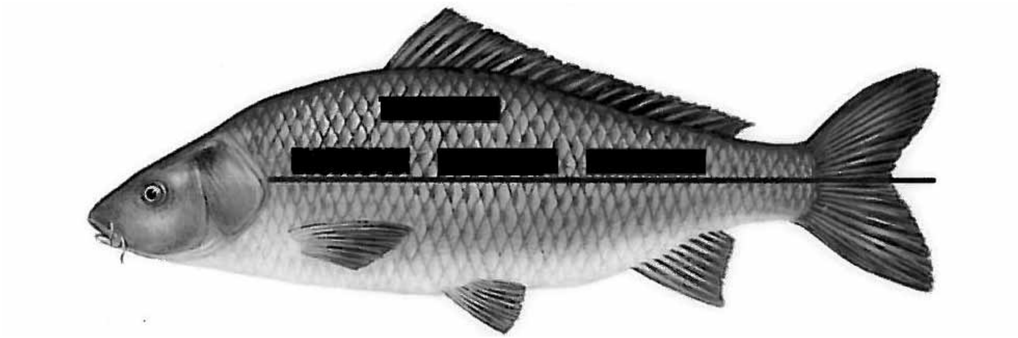

Figure 2. *Dark bands indicate the position of the instrument head for measurement of fat content (according to the manufacturer's instructions).*

Data analyses

Data were subjected to one-way ANOVA followed by Duncan's multiple range test. All data were analysed using STATISTICA 10.0 for Windows, and Spearman's ρ test was used for the analysis of correlation between weight and fillet yield and between body length and fillet yield.

Results

The main management and production data (stocking density of fish biomass, initial and final weight, cereal consumption, and calculation of production indices) are shown in Table 3. There were no mortalities during the experiment. The highest final mean weight at the end of experiment (2.26 ± 0.22 kg) was observed in carp fed pressed triticale, but there were no significant differences in production characteristics among the supplementary fed fish groups. Mean weight of carp in the control group (1.86 ± 0.21 kg) at the end of the trial was significantly lower than the supplementary fed groups.

The highest values of individual weight gain (IWG) were recorded in the treatment with pressed (1.00 ± 0.04 kg ind^{-1}) and ground (0.95 ± 0.01 kg ind^{-1}) triticale. Individual weight gain in the control group (0.65 ± 0.01 kg ind^{-1}) was significantly lower than in all other treatments. Individual weight gain in the group fed whole triticale differed significantly from both pressed and ground. The lowest mean condition factor, 3.02 ± 0.38, was observed in the control group, while the highest mean value was observed in the group fed whole triticale (3.52 ± 0.25). Lower FC values were observed in fish fed with pressed triticale and ground triticale, (3.44 ± 0.28 and 3.33 ± 0.22, respectively). The FC values differed significantly between the controls and supplementary fed groups. Differences in FC between pressed and whole grain of triticale groups were not significant, but the group supplemented with whole grain showed a significantly higher FC value compared to the ground triticale group. However values of FC in the pressed triticale group did not differ from other supplementary fed groups.

Table 3. *Management and production data: weight, Fulton's condition factor, fat content and filet yield (mean ± SD; n = 22).*

	Triticale pressed	**Triticale ground**	**Triticale (whole grain)**	**Natural food – zooplankton (control)**
Pond area [m^2]	309.6 ± 6.4	309.6 ± 6.4	309.6 ± 6.4	309.6 ± 6.4
Stocking density [$ind.ha^{-1}$]	363	363	363	363
Initial individual weight [kg]	1.26 ± 0.11^{a}	1.28 ± 0.13^{a}	1.32 ± 0.14^{a}	1.21 ± 0.15^{a}
Final individual weight [kg]	2.26 ± 0.22^{a}	2.23 ± 0.23^{a}	2.18 ± 0.24^{a}	1.86 ± 0.21^{b}
Individual weight gain [kg]	1.00 ± 0.04^{a}	0.95 ± 0.01^{a}	0.86 ± 0.03^{b}	0.65 ± 0.01^{c}
Total cereal consumption [kg]	24.75	24.75	24.75	–
Survival rate [%]	100	100	100	100
FC	3.44 ± 0.28^{ab}	3.33 ± 0.22^{b}	3.52 ± 0.25^{a}	3.02 ± 0.38^{c}
FCR	2.25 ± 0.06^{a}	2.37 ± 0.05^{a}	2.62 ± 0.07^{b}	–
SGR [% d^{-1}]	0.70 ± 0.02^{a}	0.68 ± 0.01^{a}	0.61 ± 0.02^{b}	0.49 ± 0.01^{c}
Fat content [%]	7.23 ± 1.22^{a}	6.44 ± 1.29^{b}	6.45 ± 1.33^{b}	4.6 ± 0.51^{c}
Fillet yield [%]	44.45 ± 0.95^{a}	44.33 ± 1.48^{a}	44.78 ± 1.22^{a}	41.9 ± 0.47^{b}

FC, Fulton's condition factor; FCR, food conversion ratio; SGR, specific growth rate
Values in the same row with different superscript letters are significantly different ($P < 0.05$).

The highest FCR was observed in the group fed whole grain (2.62 ± 0.07). The FCR of this group differed significantly from the groups fed pressed and ground triticale, in which FCR was similar (2.25 ± 0.06 and 2.37 ± 0.05, respectively). Use of pressed and ground triticale decreased FCR as compared to the whole grain by approximately 14.1% and 9.5%, respectively.

The lowest final individual weight (1.86 ± 0.21 kg ind^{-1}) and the lowest specific growth rate (SGR) were found in the control group, which was significantly different from supplementary fed groups (0.49 ± 0.01). The mean SGR recorded in groups fed pressed and ground triticale were 0.70 ± 0.02 and 0.68 ± 0.01, respectively.

Fat content was significantly higher in the pressed triticale group than in the other groups, and significantly lower in the control compared to supplemented groups. No significant differences were observed between groups of fish fed ground and whole triticale (Table 3).

Fillet yield was significantly higher (44.33–44.78% BW) in groups fed triticale compared to controls (41.96%) (Table 3). Fillet yield was positively correlated ($\rho = 0.59$) with weight, but no correlation ($\rho = 0.30$) of fillet yield with body length was found.

Discussion

Management data

The stocking density of common carp used in this experiment was based on long-term experience and traditional stocking density for semi-intensive culture of carp in the Czech Republic. This stocking density allows a sufficient level of zooplankton throughout most of the season (Urbánek et al., 2010).

If carps are supplemented with feed, it is very important that the used feed is suitable for common carp. Cereals can provide valuable components of nutrition in fish, as reported by Przbyl and Mazurkiewitz (2004) and Viola and Arieli (1983). Triticale (× *Triticosecale* sp. A. Camus, 1927) is an anthropogenic cereal designed to incorporate the functionality and high yield of wheat (*Triticum* spp. L) and durability of rye (*Secale cereale* L) (McGoverin et al., 2011). This cereal has already been shown to be suitable for supplementation of common carp (Urbánek et al., 2010).

Results of the present trial show that the mechanically processed triticale was associated with significantly higher IWG and SGR than found in common carp fed whole cereals or zooplankton only. This is contradicting to Przbyl and Mazurkiewitz (2004) and Przbyl et al. (1994) who found a high effectiveness of feed containing modified triticale in the intensive production of carp in ponds (initial weight 200 g ± 10 g), but no significant differences in weight gain, SGR, or FCR in fish fed diets of different cereal grains. However, Zajic et al. (2013) found FC values of 3.3–3.7 for 4-year-old common carp, and concluded that carp supplemented with cereal or rapeseed/linseed pellets had higher FC than carp on a natural diet. Our results support this interpretation. Bauer and Schlott (2009) found that Fulton condition factor (FC) as an indicator of fish condition for healthy well-fed carp was in the range of 1.9–2.2, but they used total body length (TL) for the calculation, while we used standard body length (BL). The difference is that TL refers to the length from the tip of the snout to the tip of the longer lobe of caudal fin while BL refers to the length of a fish measured from the tip of the snout to the posterior end of the last vertebra. After recalculation our values were comparable to those calculated from Bauer and Schlott (2009). Also when compared to other studies (Gela et al., 2003; Urbánek et al., 2010) using BL for calculation of FC, our values are similar (3.2–3.7 and 2.9–3.7, respectively). Urbánek et al. (2010) used the same carp breed (Třeboň scaly common carp) whereas Gela et al. (2003) used four different common carp crossbreeds.

Fat content

Final fat content of the fish can vary according to the cereal used and the amount of feed supplemented. In general, diets supplemented with cereal produce higher fat content in fish flesh compared to that in fish dependent only on natural food (zooplankton and zoobenthos) (Steffens, 1985; Urbánek et al., 2010; Zajic et al., 2013). Since cereals have a high proportion of carbohydrates as a primary source of energy (Sadowski and Trzebiatowski, 1995; Sargent et al., 2002), their oversupply results in higher deposition of fat (Yamamoto et al., 2003). Thus it is important to accurately calculate the amount of daily feed to ensure optimal fat content in carp flesh. Although better utilization of pressed cereals led to higher fat content in our study, the mean value was not above 10%. This is a critical value, as 10% fat content or higher has shown to adversely affect sensory properties of the flesh (Oberle, 1995; Oberle et al., 1997; Stein, 2005) and thus needs to be considerated from the consumers' perspective. We found a fat content in a similar range compared to other trials using cereals (table 3) as for example

6.4 and 6.9% for barley (Pfeifer and Füllner, 2005; Bauer and Schlott, 2009), 9.4 and 7.5% for rye (Oberle et al., 1997 and Pfeifer and Füllner, 2005, respectively). However in a study with carp fed maize higher fat content values of 13.3% have been reported (Urbánek et al., 2010). The fat content in fish could have been higher due to higher fat content and carbohydrates in dry matter in maize than in triticale (Urbánek et al., 2010). Reports of fat content in carp only on zooplankton vary from 1.2 to 4.6% (Oberle et al., 1997; Pfeifer and Füllner, 2005; Zajic et al., 2013), which is also in line with our findings.

Besides to diet, fillet fat content is associated with the pond management strategy. In the studies of Bauer and Schlott (2009) and Urbánek et al. (2010), ponds differed in size (6.0–57.5 ha and 1.7–2.8 ha, respectively) and different stocking densities were used (157–241 kg ha^{-1}). Urbánek et al. (2010) used carp stocking density from 379 kg ha^{-1} to 398 kg ha^{-1}. We used smaller ponds in order to be able to better maintain consistent conditions among experimental groups. Kocour et al. (2007) found also a high heritability (> 0.5) for percent fillet fat in common carp, which presents interesting prospects for selective breeding, but a strong influence of pond management and the diet remains (Fauconneau et al., 1995; Anderson and De Silva, 2003).

Fillet yield

Fillet yield of market-size common carp from European countries usually varies from 34.0 to 41.1% of BW for fillet with skin (Cibert et al., 1999; Kocour et al., 2007; Bauer and Schlott, 2009) and from 31.4 to 38.7% for skinless fillets (Oberle et al., 1997; Gela et al., 2003; Kocour et al., 2007). We observed higher mean fillet yield in fish fed modified and unmodified triticale, complementing the other favourable characteristics (FC, FCR, IWG). Compared to our results, Bauer and Schlott (2009) found lower values (34–35.4 %). This may be related to the different carp breed used or the high variation in weight of analysed carp, which is associated with maintenance during the rearing period (Bauer and Schlott, 2009). In the present study, a positive correlation between fillet yield and body weight was observed, but no correlation was found between fillet yield and body length. This is partly in agreement with Kocour et al. (2007) who reported a similar correlation (r^2 = 0.43) between body weight and fillet yield. But contrary to our findings, these authors also found a correlation (r^2 = 0.46) between fillet yield and body length. Bauer and Schlott (2009) and Cibert et al. (1999) reported neither a correlation between fillet yield and weight (r^2 = -0.16 and 0.06, respectively) no between fillet yield and total length (r^2 = -0.19). Also Cibert et al. (1999) reported carp with a wide range of weight (790–2310 g) resulting in a wide range of fillet yield (27.8–41.9%). This could be due to big range of weight. These discrepant findings indicate that there is the need of research on the relation between fillet yield, body length and body weight as well as crossbreds of common carp.

Conclusion

Based on our results, it may be concluded that common carp are able to better utilize technologically modified cereals, especially pressed and/or ground triticale, compared to whole seeds and thus reach the same or higher individual weight gain as carp subsisting on natural feed with lower FCR. This decreases feeding costs for the commercial production of common carp in semi-intensive conditions. Carp fed diets supplemented with cereals or modified cereals also showed a higher Fulton condition factor than fish on natural diet. Further research should be evaluated production and management data for other cereals used in aquaculture of common carp.

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CHAPTER 4

SUPPLEMENTARY FEEDING OF CARP WITH MODIFIED CEREALS

Másílko, J., Hlaváč, D., Hartman, P., Bláha, M., Hartvich, P., Hůda, J., Všetičková, L., 2013. Supplementary feeding of carp with modified cereals. Verified Technology, Edition of Methods, FFPW USB, Vodňany, No. 143, 27 pp. (in Czech)

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SUPPLEMENTARY FEEDING OF CARP WITH MODIFIED CEREALS

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Introduction to the problem

The common practice of pond aquaculture with carp as the "major fish" anticipates providing proper nutrition of the stock based on natural feed and supplementary feeding. Feed for carps must be efficient as well as environmentally friendly, with respect to effects on water, which is seen as "precious possessions" (Directive 2000/60/ES, 2000 of the European Parliament and of the Council). Water, including retained water, is a factor of production in fish farming, but is not the subject of property. Companies involved in aquaculture are in the state of "limited resources and capabilities" and their prosperity is related to their level of economy income.

Breeding of market carp should fulfil the purpose of the production of whole foods, while respecting the laws in force and using scientific and technical knowledge. The certified technology summarizes new findings related to the efficiency of a traditional treated animal feed – cereals, which have been applied successfully in the nutrition of carp. The technology describes a technique of feeding and the influence of the physiological process of conversion carp feed on the balance of phosphorus in water, as the main element of eutrophication. Monitoring feed efficiency is the subject of controlling water quality and the welfare of farmed fish.

1.1. Supplementary feeding of carp

1.1.1. Importance of natural and supplementary feeding in carp farming

Fish production in ponds in the Central Europe is achieved mostly by semi-intensive farming combining natural and supplementary feeding, mainly cereals (Hepher and Pruginin, 1982; Moore, 1985; Horváth et al., 1992; Kaushik, 1995; Bauer and Schlott, 2006; Adámek et al., 2010; Mareš et al., 2012). Natural food plays an irreplaceable role in the diet of carp. In terms of nutritional levels, it contains easily digestible proteins, mainly from representatives of zooplankton and zoobenthos. This natural food is of good quality and contains all the components necessary for normal growth of fish (Jirásek et al., 2005). It is known that aquatic invertebrates contain large amounts of protein (55–70% of dry matter), necessary for good growth of older carp which need usually 25–30% of protein (Hepher, 1979; Wieniawski, 1983; Kaushik and Preface, 1995; Jirásek et al., 2005). It is apparent that protein from natural feed is not always fully economically used for the growth of fish. Supplementary feeding in ponds creates an increase from 25–30% (Adámek et al., 2008) to 50% (and more) of biomass of fish (Tacon and De Silva, 1997; Szumiec, 1999). The rest of the production arises from natural feed. Supplementary feeding is a useful source of nutrients and energy for carp and adds the necessary components for better growth and production of fish (Abdelghany and Ahmad, 2002). The semi-intensive farming system uses feed of plant origin, such as rye, triticale, maize, wheat and barley (Hůda, 2009; Jankovic et al., 2011). However, such feed does not cover all needs necessary for nutrition and growth of farmed carp although the cereals are cheap and an easily available source of energy (Ghosh et al., 1984; Turk, 1994, 1995; Markovic and Mitrovic-Tutundzic, 2003; Hůda, 2009; Mráz and Picková, 2009).

Starch is an essential component of cereals (60–70%), its digestibility for carp is of about 70% if the cereals are unprocessed (Cirkovic et al., 2002) however, it can be increased to up to 90% by a heat treatment (Przybyla and Mazurkiewicz, 2004). A specific enzymatic system with high amylase and maltase activity allows the carp to use high amounts of carbohydrates (Steffens, 1985). Thanks to their high digestibility, carbohydrates are one of the most valuable sources of energy in feeds for carp and enable better utilization of protein for fish growth (Sadowski and Trzebiatowski, 1995). Total protein content in the grains of cereals varies depending on the type and quality in the range of 7–15% (Füllner et al., 2000; Dordević and Dinić, 2007). On the other hand, the protein composition is poor in essential amino acids (Przybyl and Mazurkiewicz, 2004; Másílko and Hartvich, 2010). Hofer and Sturmbauer (1985) mention that wheat and some other cereals contain anti-nutritional substances (albumin, etc.), which reduce the α-amylase activity. These substances may reduce the digestion of starch. Anti-nutritional factors mainly include protease inhibitors, phytoestrogens giotrogeny, antivitamins, phytates, various oligosaccharides and antigenic proteins – allergens (Tacon and Jackson, 1985; Hendricks and Bailey, 1989; Macrae et al., 1993; Liener, 1994; Anderson and Wolf, 1995; Friedman, 1996; Alacrón et al., 1999). The effects of anti-nutritional factors are undesirable because they reduce feed intake and bioavailability of nutrients from the diet, thus they cause the reduction of the growth and higher water pollution by excreted faeces (Van der Ingh et al., 1996; Refstie et al., 1998; Alacrón et al., 1999; Arndt et al., 1999). A fundamental reason is the absence of enzymes. As for example, phytic acid, the stored form of phosphorus in plant feed, creates complex compounds called phytates with some elements (e.g., Ca, Mg, Zn). The proportion of phytate phosphorus, which is significantly indigestible for monogastric animals, of total phosphorus in the wheat grain is 73% (Kudrna, 2004). To be used by fish, this phosphorus must be released from the complexes by enzymatic hydrolysis through the phytase enzyme. The feed of plant origin contains an insufficient amount of phytase and fish is not able to produce this enzyme. Phytases produced by microorganisms may be added in feed or feed mixtures. Higher utilization of phosphorus from plant components leads to a reduction in the need to add inorganic phosphates in feed mixtures (Rodehutscord and Pfeffer, 1995; Oliva-Teles et al., 1998).

1.1.2. Stability of production in pond aquaculture

Research on and implementation of nutritional strategies to reduce the production of metabolites in ponds is one of the factors that influences the sustainability and stability of pond aquaculture production. Steffens (1985) dealt with the assessment of protein from feed and their conversion into biomass of carp under operating conditions, showing that the deposition of proteins in two-year old carp fed industrially produced feed mixtures based on cereals is in the range of 27–32%, which is relatively low. Similar results were reported by Máchová et al. (2010). In our study, in order to verify the technology, the quality of the feed, its appearance and the applicability of this technology to increase carp stocks have been analysed recently (Hossain et al., 2001, Másílko et al., 2009, Davies and Gouveia, 2010). Type, composition and production method of feed have a significant impact both on the retention of nutrients in fish biomass and, reciprocally, on the amount of metabolites produced by fish stocks in the ponds (NRC, 1993; Jirásek et al., 2005). Improving the quality of feed in order to retain phosphorus in the fish biomass is one of the main objectives in order to reduce the impact of aquaculture on the environment (Gavin et al., 1995, Satoh et al., 2003). From the perspective of excessive nutrient loading of pond ecosystems used for fish farming, it will be important to adjust the amount of feed and fertilizer to reach a zero balance of phosphorus in ponds (TP in feed + TP in fertilizer + TP in fish stock = TP in harvested fish). In such case, all of the phosphorus supplied to the pond in connection with fish farming would be removed from the water again by the biomass of fish. No "extra" phosphorus would be supplied increasing its concentration in the surface water and thus the water eutrophication (Knösche et al., 2000; Duras and Potužák, 2012; Hartman, 2012). Due to the thermal instability of anti-nutritional substances (e.g. lectins and protease inhibitors), it is possible to reduce, limit, or inactivate their function without a depreciation of the feed material using a heat treatment (Másílko and Hartvich, 2010). Some anti-nutritional substances may be present in the hull of the cereals. Therefore, removal or disruption of hull and subsequent heat treatment of certain feed can significantly reduce the impact of these factors (Robaina et al., 1995; Burel et al., 1998; Refstie et al., 1998; Glencross et al., 2007). In accordance with these conclusions, it is expected that thermal or mechanical processing of feed cereals before using them in carp ponds can help to increase the digestibility of such modified cereals and to reduce the load on the pond environment by undigested or poorly digested feed supplements (Jovanovic et al., 2006; Hlaváč et al., 2014), and thus relieve the nutrient balance of the ponds.

1.1.3. Supplementary feeding of stocks in relation to current legislation

Pond aquaculture from the sixties up to the nineties of the 20th century was focused on stocking and feeding with granular feed mixtures containing a proportion of animal protein. The current pond aquaculture returned to the original method of the supplementary feeding of carp with cereals. The reason for feeding cereals is their characteristic stability against nutrient leaching in opposite to industrially produced feed mixtures in the form of granules.

The significantly different digestibility and retention of protein, fat and carbohydrates from natural feed and supplementary cereals in the biomass of carp is equally important. Schäperclaus and Lukowicz (1998) report a recoverability for protein up to 90% and fat based on unsaturated fatty acids up to 95% from zooplankton, while the protein utilization of cereal (depending on fibre content) is in the range of 30–45% by common carp. For the above mentioned, the efforts for more efficient utilization of cereals by increasing their digestibility and the nutrient conversion are completely justified, both in terms of fish farming, and for the interests of the protection of surface waters (Knösche et al., 2000; Duras and Potužák 2011; Hlaváč et al., 2014). Currently used methods in feed production are very effective, in order to improve dietary characteristics, digestibility, eliminate anti-nutritional substances and to extend the shelf life (Kudrna, 2004). The available treatments for carp feed were evaluated in 2009–2012 including thermal treatment (hygienization), pressing of cereals, heat treatment simultaneously with pressing and grinding of grains (Hartvich and Urbánek, 2007; Urbánek, 2009; Hůda, 2009; Másílko et al., 2009, 2010) together with the influence of supplementary feeding on the nutrient balance in ponds (Hartman, 2012; Hlaváč et al., 2013).

2. Aim

The primary concern in the management in pond aquaculture with fish production is the efficient utilization of material inputs, such as feed and nutrients for the development of pond biocenosis. This is also important in regard to the requirement of an environmentally-sound cultivation practices of the surface water, which results in sustainable development of fish ponds.

The aim of the technology is to provide expertise about the effectiveness of modified cereals compared to unmodified cereals in pond common practice of carp farming.

It is necessary for sustainable fish farming in ponds to prevent cumulating of nutrients in ponds or pond basins due to fish increment. On the other hand, it is desirable to convert the nutrients into the biomass of the fish growth and to eliminate them from the water.

3. Place where technology was certified

The technology was certified in 2009–2012 in Rybářství Třeboň a.s. The evaluation was done in the storage ponds in Třeboň (Figure 2) – objects providing a controlled environment without flow, excluding the impact of basin or minimizing the effect of nutrient sources in sediments and in four flow-tight ponds (Figure 1) – in pond systems Naděje, near Frahelž (2012), Horák (2,2 ha), Baštýř (1.7 ha), Fišmistr (2.8 ha) and Pěšák (2.7 ha). Management in those ponds matched operating conditions of normal pond practice, but without fertilization.

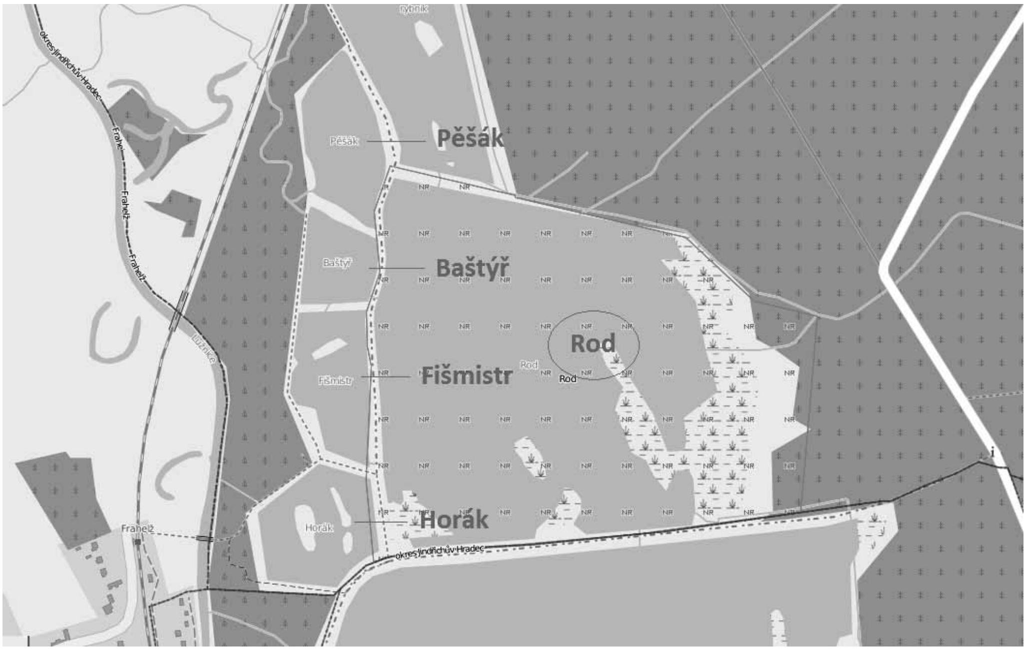

Figure 1. *Ponds near the village of Frahelž (source: www.openstreetmap.org).*

Figure 2. *Preparation of holding ponds for evaluations in Třeboň (Photo: D. Hlaváč)*

4. Description of the technology and results

4.1. Evaluation of the „novelty of the procedure"

A digestibility between 60–86% of untreated cereals by two and three-year old carps was achieved under suboptimal water temperature (19–22 °C) but optimal oxygen content (70–75%). However an absorption of nutrients into the muscles of carp reached a maximum of 32% in operating conditions (Steffens, 1985).

The search for options how to ensure a better digestibility and absorption of cereals by fish is therefore justified primarily in terms of economic efficiency of feed and also for the reduction of metabolism products of carp stocks with regard to the protection of the aquatic environment. A carp digests most of fibre and some other polysaccharides and plant proteins with difficulties because of the absence of a stomach and its functions (Jirásek et al., 2005). The current method of traditional pond aquaculture is based on the supplementary feeding of untreated whole cereals. Earlier the only possible treatment of cereals consisted of soaking the cereals in a vessel with a volume of water equal to the weight of the grains (for legumes usually a volume of water to 2.5 times the weight is used). The technology compares whole cereals without modification and heat-treated cereals (Figure 7) labelled as hygienized, pressed cereals, cereals pressed and simultaneously heat-treated cereals and rough grinding. Heat treatment of feed in principle means to apply an action of heat or heat combined with moisture to the feed. Starch, which is present in abundance in the cereals begins to swell at a temperature of 50–60 °C (Doležal et al., 2006). The temperature up to 120 °C with 20% moisture is more appropriate for greater degree of gelatinous. This results into better digestibility of feed (starch is partially hydrolyzed and more easily accessible for digestive enzymes).

For that reason, the heat treatment was used in our evaluation. The heat treatment is executed with hot steam at the temperature of 95–100 °C followed by 60–90 seconds in the hygienizer at a temperature ranging from 75 to 85 °C and under the pressure of 0.2 MPa. After cooling the cereals are placed in a container for further dispatch. Hygienisation secures an increase in the digestibility of polysaccharide – mainly of the starch by gelatizing of 60–90% of the original content. This method is known as the HTST (High Temperature Short Time). The feed is processed gently, without adversely affecting the natural shell of the grains and thus its "water resistance". The heat treatment of cereals (legumes or oilseeds) took place in a continuous process (Kudrna, 2004) and used an equipment manufactured by Bühler AG (Switzerland – Figures 3 and 4).

The effect of **hygienisation of feed** is the preparation of feed with improved dietary properties. This is done primarily by increasing the digestibility of each of the components, reducing the content of anti-nutritional substances and elimination of undesirable microorganisms. It leads also to extend the shelf life of the feed.

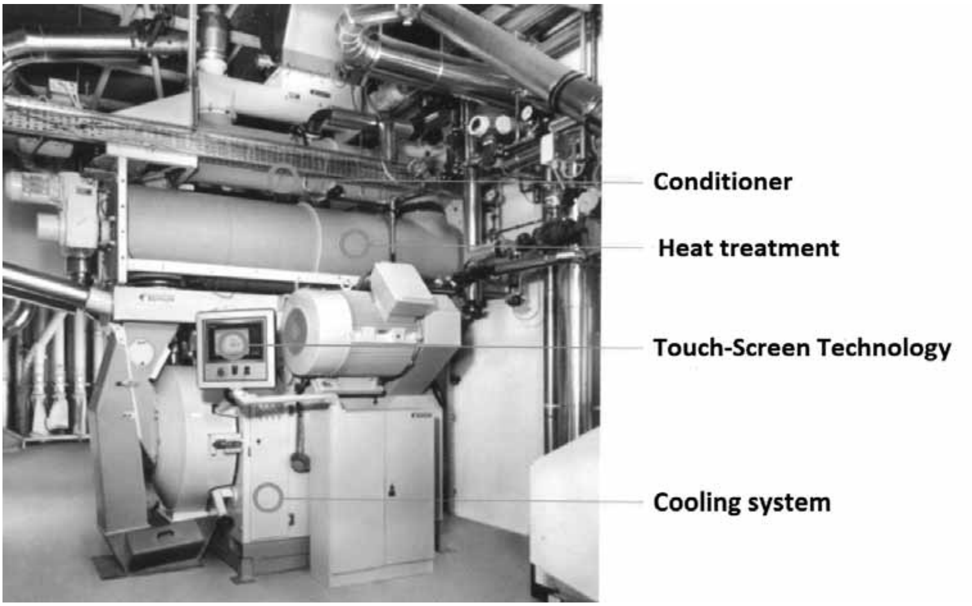

Figure 3. *Hygienisation system (heat-treatment of cereals) according to technical documentation of Bühler AG, Switzerland.*

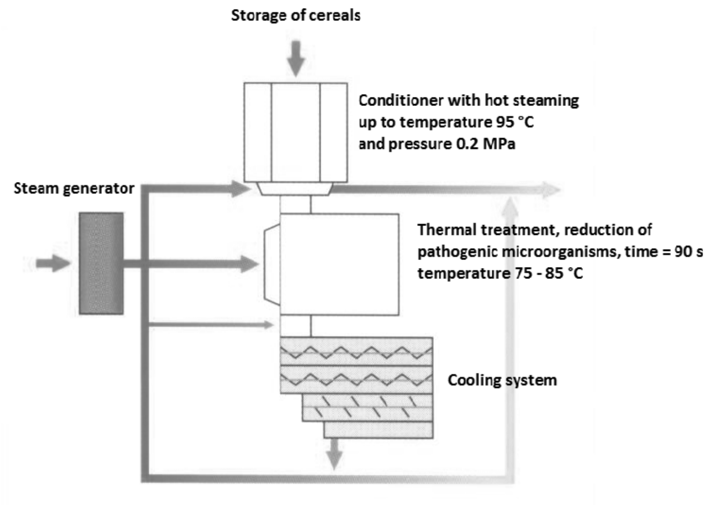

Figure 4. *Scheme of the heat treatment of cereals according to technical documentation of Bühler AG, Switzerland.*

Pressing of cereals is executed by smooth rollers, moving against each other, the distance can be adjusted as needed pressure on the grains. Squeezing undermines the integrity of the grains by compression (Figure 8), thus facilitating its digestibility especially for carps of lower ages (farming of K1 to K2) with weights up to 200 to 250 g per carp. Pressing of cereals can be considered as a first stage of grinding which generally represents a major mechanical treatment of the grain.

Grinding is a violation of surface packing of a grain, which leads to the reduction of undesirable anti-nutritional substances which are contained in the grain (Tacon and Jackson, 1985). The size and particle size balance influences the efficiency of feed and the amount of processing costs. Preparation and treatment of grain feed is very demanding on the required energy input. Therefore, the appropriate solution in order to save energy is very important. In practice, the feed includes three levels of grinding with the following particle sizes: coarse (> 2.0 mm), medium (1.0 to 2.0 mm) and fine (< 1 mm) (Másílko et al., 2009). Grinding of animal feed provides better feed intake and increases the digestibility (Urbánek, 2009). Čítek et al. (1998) describe that the goal of grinding is the adjustment of particle size according to the size and needs of the fish fed with the supplementation. The positive effect of grinding (Figure 9) is the improvement of the digestibility. Some losses occur due to dissolution in the water (up to 30% or more) and leaching of elements (up to 50%) from the grounded grains. Solved particles then decrease water quality and increase the eutrophication of a pond.

4.2. Material and Methods

4.2.1. Supplementary feeding of carp by technologically modified cereals

Feed was given to monoculture stocks of K_3 with the initial weigh of 1 ± 0.3 kg per individual, three times a week (Monday, Wednesday and Friday) from May to September (160–170 days). Stocking density was 363 $ks.ha^{-1}$ of weight-balanced individuals of carps; corresponding to 350 $kg.ha^{-1}$ of biomass. Cereals (wheat, triticale and rye), unmodified, thermally treated, pressed, grinded, or treated with a combination of heat treatment and pressing were used. The tests were done in storage ponds in Třeboň and in four flow-tight ponds in Naděje, a pond system near the village of Frahelž. Annual (vegetation) feed ration of cereals accounted for 3 kg of tested feed per 1 kg of carp during stocking. Current feed ration of feed administration was at the level of 2–5% with respect to the growing season, water temperature, oxygen content and the actual weight of the stocking found by the previous control catching. The level of development of natural feed was also taken into account in the ponds. The nutritional value of feed was determined by the producer and an independent accredited laboratory in the respect of crude protein, Nitrogen-Free Extract (NFE), fat, digestible energy (DE) and total phosphorus (TP).

Before the beginning and after the end of each experiment, the total weight of the fish stock was assessed. Subsequently, the feed conversion ration **FCR** rate was calculated by the following formula:

$$\mathbf{FCR} = \frac{F}{(w_t - w_o)}$$

w_t .... weight of fish stock at the end of the experiment [kg]
w_o .... weight of fish stock at the beginning of the experiment [kg]
F .... amount of feed during the period [kg]

To evaluate the efficiency of treated feed in relation to the untreated feed, the following calculation was then used to calculate U_k increase in conversion in % (feed efficiency in %) according to the FCR:

$$U_k = \frac{(FCRU + FCRUk_n) \times 100}{FCRN_{k1} + FCRN_{kn}}$$

$FCRU_{k1} – FCRU_{kn}$ .... FCR modified feed during the monitoring *1* up to *n*
$FCRN_{k1} – FCRN_{kn}$ .... FCR unmodified feed during the monitoring *1* up to *n*

4.2.2. Calculation of the phosphorus balance

To calculate the phosphorus balance (as a major nutrient causing the development of eutrophication and algal blooming), it is necessary to know the input of these elements by supplementary feeding of cereals. Monitoring included an analysis of the feed nutrients to focus on the TP content in the dry matter of feed.

According to the analysis of feed (2012), the untreated wheat contained 3.15 $g.kg^{-1}$ of TP. The heat treatment increased the content to 3.25 $g.kg^{-1}$ of TP. The difference in the content of total phosphorus in treated wheat was caused by partial loss of water during the heat treatment. To calculate the balance is also important to determine the content of the main element in the biomass of fish in order to quantify the output of nutrients by the fish production.

The analysis was based on data showing that 1 kg of fish biomass contains 8.4 g of TP (Hlaváč et al., 2013). The method of the assessment of the balance of nutrients (by Duras and Potužák, 2012) is shown in Figure 5. The calculation used data of the pond from 2012. The balance was calculated with respect to the input and output of TP in feed and fish biomass without taking into account the inputs and outputs of the inlet and outlet of the water.

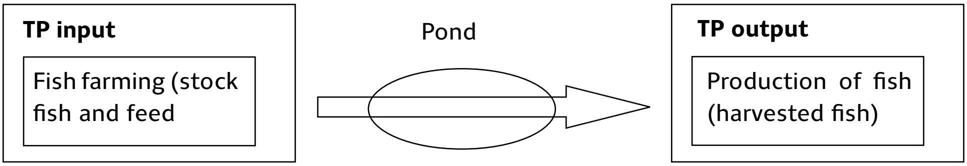

Figure 5. *The basic shceme for evaluating the balance of matter.*

The critical value of the feed conversion rate (FCR_k) was calculated by the proportion of the TP content in the feed and in fish biomass according to Hejzlar et al. (2007), which shows the ratio between the concentration of TP in the fish biomass and the nutrient concentration present in the feed according to the following formula:

$$FCR_k = \frac{Cr}{Ck}$$

Cr .... concentration of the element in fish biomass
Ck...................... concentration of the element in the feed

Example of calculating the balance of phosphorus

The retention of total phosphorus in the fish biomass is shown in Table 1. The output of phosphorus in harvested fish was always higher than the input by feed and the initial fish stock. The highest retention (-2985 $g.ha^{-1}$), i.e. output of phosphorus in fish biomass was recorded in control group (only on natural feed) with zero input of phosphorus by the feed. The fish stocks supplementary fed heat-treated wheat had the highest retention (-1877 $g.ha^{-1}$) compared to the other supplementary fed groups of fish. The lowest retention was recorded in ponds where fish were supplementary fed by wheat without modification (-1301 $g.ha^{-1}$). Furthermore, the value of the critical threshold for the feed conversation rate was calculated (FCR_k = ratio exmashing the content of TP in the growth of the fish to TP content in the feed). The critical factor of feed for wheat without treatment was 2.67 (8.4 $g.kg^{-1}$ of TP in fish / 3.15 $g.kg^{-1}$ of TP in wheat) or wheat after heat treatment is 2.58. According to the obtained coefficients of unmodified wheat, the real FCR was 1.94 and 1.69 for wheat after heat treatment in the ponds. A rational supplementary feeding of the fish stock was performed with regard to the balance of phosphorus in the ponds, without exceeding the critical value of the feeding rate for TP could be concluded.

Table 1. *Example of calculating the balance of phosphorus in the ponds in 2012.*

Feed	Input initial fish stock [g.ha^{-1}]	Input feed [g.ha^{-1}]	Output harvested fish [g.ha^{-1}]	Total balance [g.ha^{-1}]	FCR	Total weight gain of fish [kg.ha^{-1}]
Heat-treated wheat	2290	3562	7729	**-1877**	1.69	644
Untreated wheat	2397	3441	7139	**-1301**	1.94	563
Control	2426	–	5411	**-2985**	–	355

4.2.3. Physical and chemical properties of water and natural feed of fish

Since 2009, the physical and chemical water parameters temperature, oxygen and pH were monitored in the experimental objects (storage ponds and ponds) at fortnightly intervals in the storage ponds and 5 times during the growing season in the other ponds during the feeding experiment. To measure the physical and chemical properties of the water the YSI Professional (Yellow Spring, USA) was used.

Water properties in the storage ponds and the normal ponds are shown in Tables 2 and 3. According to the values observed all water quality parameters were suitable for good growth of carp during the experiment.

Table 2. *Physical and chemical parameters of water (holding ponds in Třebon, 2009–2012).*

Year	Water temperature (°C)	Oxygen (mg.l^{-1})	pH
2009	20.6 ± 2.9	5.4 ± 0.7	7.3 ± 0.9
2010	21.0 ± 2.7	6.2 ± 1.6	7.2 ± 0.4
2011	20.6 ± 2.7	7.0 ± 1.0	8.1 ± 0.5
2012	20.6 ± 2.4	6.3 ± 1.1	8.1 ± 0.6

Table 3. *Physical and chemical parameters of water (ponds 2012).*

Pond	Feed	Water temperature (°C)	Oxygen (mg.l^{-1})	pH
Horák	Heat-treated wheat	20.2 ± 5.3	8.2 ± 1.8	7.9 ± 0.8
Fišmistr	Untreated wheat	22.2 ± 5.0	8.6 ± 1.8	8.2 ± 0.8
Baštýř	Control	20.5 ± 5.3	9.7 ± 0.8	8.4 ± 0.5
Pěšák	Heat-treated wheat	22.0 ± 4.5	7.7 ± 1.7	7.8 ± 0.7

Zooplankton samples were collected in the ponds used for the experiment for quantitative and qualitative analysis. For the collection of the zooplankton in the storage ponds a plankton throw net of 80μm mesh size was used. Samples were made with a five-metre lines and preserved in 4% formaldehyde. The analysis was performed in the Sedgwick-Rafter cell counting chamber. The sample of zooplankton from the ponds was filtered through a sieve with a mesh size of 700 μm. The resulting fraction was transferred to a graduated cylinder. After 30 minutes of sedimentation the zooplankton was condensed to the volume of one litre. To calculate the weight and dry weight the following relation was used: 1ml of the zooplankton = 0.5 g of fresh weight. In the Naděj pond system, quantitative samples of macrozoobenthos

(Figure 6) were collected as well in 2012. Samples were collected by the Ekman-Birge bottom sampler with grasping area of 225 cm^2. Four samples were collected in each of the ponds and individually rinsed on a mesh size of 0.5 mm immediately, and the remaining sediment with benthic organisms was preserved as a sample in 4–6% formaldehyde. The density and biomass of the zoobenthos was recalculated for one square meter area of the bottom. Monitoring of the macrozoobenthos in storage ponds was not done because due to the mineral substrate of the bottoms (sand), no significant presence of higher aquatic invertebrates occurred.

Feed Supply – zooplankton (storage ponds in Třeboň, 2009-2012)

Storage ponds 2009

Average abundance of the zooplankton (Rotifera, Cladocera, Copepoda) was to 488 ± 294 ind.l^{-1}, the lowest content was observed in September (82 ind.l^{-1}). Throughout the season the dominant group was Daphnia (Cladocera 69%), mainly the *Daphnia longispina*. The amount of *Daphnia* larger than 0.7 mm during the growing season was highly variable and fluctuated from a maximum of 250 ind.l^{-1} in July to 3 ind.l^{-1} in August.

Storage ponds 2010

A mean value of 204 ± 127 ind.l^{-1}, of zooplankton was observed. *Daphnia* (mainly *Bosmina longirostris*) dominated throughout the whole season (83%). Copepods (Copepoda) accounted for about 13% of the total plankton communities and were represented mainly with the dominant copepod species *Thermocyclops crassus*. Rotifers (Rotifera) represented only 4% of the total abundance. The quantity of *Daphnia* larger than 0.7 mm were in the order of a few specimen recorded in June (3 ind.l^{-1}) and a maximum in August (20 ind.l^{-1}) with *D. longispina* as the dominant species.

Storage ponds 2011

The average value of total the zooplankton was 181 ± 245 ind.l^{-1}. The lowest amount was observed in August (43 ind.l^{-1}), when the community was dominated by daphnia (mainly *D. longispina*). The highest content of zooplankton was found in September (798 ind.l^{-1}), when the copepods dominated the zooplankton with a proportion of 83%. The abundance of daphnia larger than 0.7 mm represented mainly by species *D. longispina*, was in the order of several specimen (average of 5 ± 2 ind.l^{-1}).

Storage ponds 2012

The mean value of the zooplankton was 84 ± 82 ind.l^{-1}. According to the proportion of each group, the population was dominated by copepods with 60%, represented mainly by cyclopoida. Daphnia accounted for 34%, with *D. longispina* as the dominant species. Rotifers accounted for only 6% of the total abundance of the zooplankton. The highest amount was found in July (189 ind.l^{-1}), while the lowest amount of the zooplankton was recorded in September (26 ind.l^{-1}). *Daphnia* greater than 0.7 mm were predominantly represented by *D. longispina* (9 ± 9 ind.l^{-1}).

The quantity the zooplankton (especially individuals larger than 0.7 mm) was lower in the control (no supplementary feeding), while in the ponds with different types of supplementary feed a significantly higher quantity of zooplankton was found, although this also fluctuated in different years.

Feed supply – zooplankton and zoobenthos (experimental ponds 2012)

Specimen bigger than 0.7 mm were represented in all experimental ponds by *Daphnia galeata* during the major part of the growing season, to a lesser extent also by species of *Ceriodaphnia sp*. and *Daphnia pulicaria* (Table 6). The ponds provided enough natural feed for almost the whole season and an almost optimal feed conversion was achieved. The pond of Baštýř (without supplementary feeding) clearly showed lower presence of the bigger zooplankton specimen (Table 4).

Table 4. *Abundance of the zooplankton in ponds, 2012 (g.m^{-3}).*

Feed	**zoopl. > 0.7 mm (g.m^{-3}) průměr**	**zoopl. > 0.7 mm (g.m^{-3}) minimum**	**zoopl. > 0.7 mm (g.m^{-3}) maximum**
Heat-treated wheat	1.72	0.69	3.67
Untreated wheat	1.83	0.23	5.50
Control	1.03	0.23	3.67

Macrozoobenthos in the ponds in 2012 consisted of 23 taxa, ten of which were found in the control pond, 15 of them were found in the ponds with supplementary feeding. All 10 taxa occurring in the control pond were common to all samples. Differences in the number of taxa identified in individual samples were not significant between the samples.

The density and biomass of benthic invertebrates was higher in samples from the ponds with supplementary feeding compared to the control pond. Differences were found when comparing the index of saprobity (SI) – while its value by macrozoobenthos showed worse alfa-mezo-saprobity in the control pond (SI 3.46 ± 0.17) ponds with supplementary feeding indicated water quality by about a half degree better (SI 2.79 to 2.98). The diversity index of macrozoobenthos reported no differences; the values were, however, overall, slightly lower in ponds with supplementary feeding (Table 5).

Table 5. *Analysis of benthos in ponds in 2012.*

Feed	**Control**	**Untreated wheat**	**Heat-treated wheat**
density [ind.m^{-2}]	411 ± 154	907 ± 353	863 ± 561
biomasss [g.m^{-2}]	1.89 ± 0.83	2.89±1.37	3.68 ± 2.74
Number of taxa	5.6 ± 1.7	7.2 ± 2.6	6.7 ± 3.1
Sum of taxa	10	15	15
SI	3.46 ± 0.17	2.98 ± 0.51	2.79 ± 0.54
H´	1.32 ± 0.23	1.27 ± 0.41	1.10 ± 0.45
The dominant taxa	Tubifex tubifex Limnodrilus hoffmeisteri Chironomus plumosus Ceratopogonidae	*Tanytarsus* sp. Tubifex tubifex *Limnodrilus* sp. Ceratopogonidae	*Tanytarsus* sp. *Chaoborus* sp. *Limnodrilus* sp. Ceratopogonidae

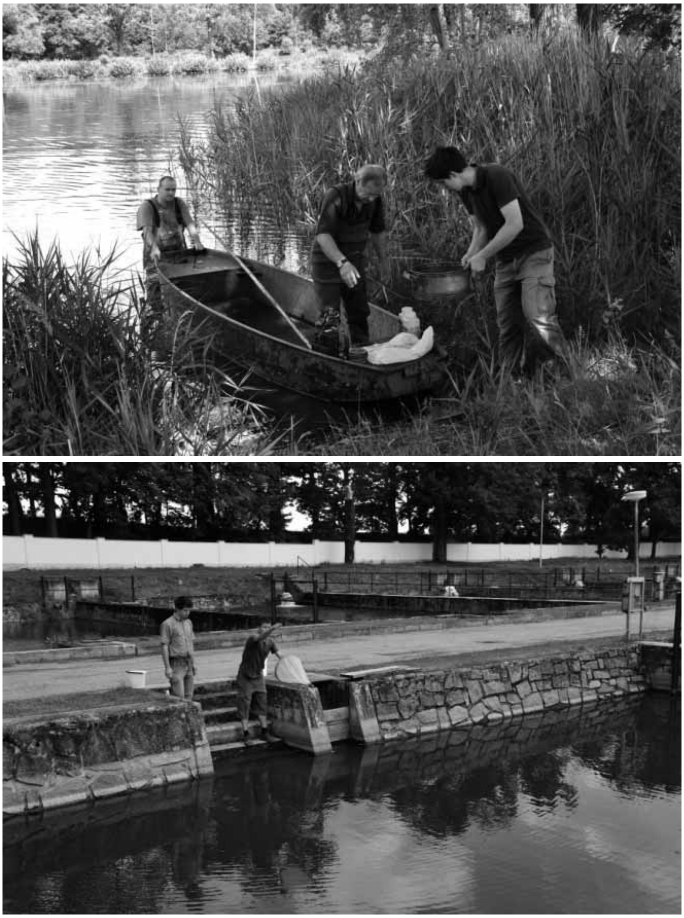

Figure 6. *Sampling of plankton in storage ponds of Třebon and sampling of benthos in ponds of Naděj system (Photo: D. Hlaváč and M. Podhradská).*

4.3. Results of supplementary feeding of carp with treated cereals

The aim of aquaculture today is to ensure an adequate production of fish and aquatic animals. One option for achieving this goal is a technological modification of cereals in order to increase the digestibility and the nutritional value while preserving the natural shell of the cereals, ensuring their water resistance until their consumption. The research was carried out in storage ponds, which are characterized by flow-tightness and relatively low natural production without being affected by input of nutrients, and in normal ponds (Table 6).

In the experimental storage ponds, the efficiency of heat treated cereals resulted in an improvement of the feed conversion of 9.73% at a relatively low natural production level of 185 $kg.ha^{-1}$ in average. The results were reported after seven tests. In contrast, the heat-treated cereals in the ponds showed to improve feed conversion by nearly 13%. However, this can probably be attributed to the higher natural feed production in these ponds compared to the natural feed production in the storage ponds (371–372 $kg.ha^{-1}$). Heat-treated cereals in accordance with a sufficient supply of natural food are suggested to be quite positively for the increase of fish biomass.

Heat treated and pressed cereals resulted in an improved feed conversion of 7.93%, after three tests. This was marginally lower compared to heat-treated cereals. Also pressed cereals improved the feed conversion rate (FCR) by 10.34% compared to untreated whole grains. Since pressing the cereals is not expensive, but unfortunately reducing the shelf life, these treatment can be used especially for K_1–K_2 (age categories of carp). Supplementary feeding by grinded cereals reported insignificantly better feed conversion expressed as more efficient FCR by 2.93% (with a medium to coarse grinding after eight tests in holding ponds in 2009–2012). The research of supplementary feeding by grinded cereals was not realized in ponds due to insufficient soaking of gristle and resolving of the cereals in the water.

Table 6. *Summary of the average values of the FCR (± SD) and the effectiveness of technologically modified feed (U_k) in the storage ponds and ponds in 2009–2012.*

Experimental objects	Heat-treated	Untreated	Pressed	Untreated	Heat-treated and Pressed	Untreated	Grinded	Untreated
Storage ponds	2.23 ± 0.13	2.47 ± 0.09	1.77 ± 0.50	2.00 ± 0.40	2,24 ± 0,14	2,43 ± 0,10	1,85 ± 0,73	1,91 ± 0,64
U_k FCR [%]	**9.73**		**10.34**		**7.93**		**2.93**	
*Ponds	1.69 ± 0.0	1.94**	–	–			–	–
U_k FCR [%]	**12.89**		–		–		–	

* FCR scored on the ponds was recalculated using the weighted average in relation to their area (ha)
** Without repetition

An example of the calculation of efficiency (U_k) of technologically modified cereals (Fm) is given below (coefficients of modified feed cereals in the numerator and untreated cereals (Fs) in the denominator are in brackets)

Example.: $\boldsymbol{U_k}$ (storage pond) $= 100 - \dfrac{(2.05 + 2.35 + 2.04 + 2.23 + 2.43 + 2.2 + 2.29) * 100}{(2.55 + 2.63 + 2.36 + 2.38 + 2.45 + 2.45 + 2.45)} = 9.73\%$

Figure 7. *Heat treatment – hygenisation of cereals. This method of cereal treatment is indistinguishable from the whole grains. The only chance to detect heat treated cereals is to check the germination. The cereals are not able to germinate after hygenisation process. (Photo: J. Másílko).*

Figure 8. *Mechanical treatment of cereals by pressing. (Photo: J. Másílko).*

Figure 9. *Mechanical treatment of cereals by grinding. (Photo: J. Másílko).*

4.4. Assessment of supplementary feeding of carp with modified cereals

1. Heat treated cereals showed a more efficient conversion of nutrients during the growth of carp in both storage ponds and also in the normal ponds. This confirms that the carp as an agastric animal can use hygienized cereals significantly more efficiently by about 10–13% compared to cereals without modification. Improved dietary characteristics of the heat treated cereals together with a sufficient supply of natural food resulted in a more efficient conversion of nutrients to fish biomass. Humid heat treatment of cereals by the hygienisation process showed an increased digestibility and an increased conversion of nutrients by the fish. Finding new ways to tailor the feed and the confirmation of the feeds suitability for pond aquaculture production seems to be promising for the future.

2. Pressing of cereals, which disrupts the natural protective shell – a husk of caryopsis, makes nutrients in the endosperm better available and partially removes anti-nutritional properties of a grain. This treatment resulted in positive results in the storage ponds, increasing the feed conversion up to 10%. The ponds can be affected in particular by the possibility of dissolving in the water, similarly to cereals modified by grinding. This method of treatment is therefore more appropriate in smaller ponds and fingerling ponds with the recommendation to feed into feed frames.

3. Feeding heat-treated and pressed cereals together resulted into improved conversion by nearly 8% (7.94%) in holding ponds and corresponded with the pressing of cereals. However, applying this adjustment for market carp feeding in the main ponds is at least questionable with regards to possible dissolving in the water and increased costs.

4. Coarsely and medium grinded cereals were observed to be insignificantly positive (3%) for the conversion of nutrients by the fish in the storage ponds. The experiments were not tested in the ponds because of the known dissolving of such treated cereals in the water.

5. Balanced nutrient management in ponds is achievable assuming the exploitation of natural food and an adequate supplementary feeding at up to twice the level of the natural output. To focuse on the nutrient balance in the ponds is not only a tool to optimize their use, but also an opportunity to improve the management of the entire pond system. Different modifications of cereals listed in this technology may be a framework for the sustainable management of pond resulting in an improved phosphorus balance in the pond systems.

4.5. Store and dealing with treated cereals

Storage is a very important aspect for mechanically treated cereals. A long-term storage leads to a wide variety of undesirable biochemical, chemical or even physical changes (Skalický et al., 2008). Disrupting the integrity of the caryopsis enables easy contamination by the surrounding environment. Therefore, it is particularly important to store mechanically processed cereals in clean, dry and ventilated area. Mechanical treatment of cereals is subject to the current need for feeding fry and stocks. It is not recommended to store the modified cereals as reserves for very long time. Furthermore, pressed cereals have a lower specific weight. According to Mareš et al. (2011) pressing reduces the specific weight of up to 30%.

Reducing the specific weight increases the demands on the application for example feeding into enclosed frames.

Cereals treated by hygienisation leave the production process chilled with a lower water content stabilized against external influences during storage. Due to the reduced moisture cereals are protected against for exampleagainst fungal diseases orgermination of grain caused by increased digestibility of the polysaccharides due to the reduced moisture. Logistics related to the storage, and application is comparable to the standard cereal feeds.

5. Economic benefits of technology to the business entity

The cereals treated by hygienisation resulted into a significant reduced FCR (Food Conversion Ratio) = the ratio between the consumed food and fish growth) of 9.73% in the storage pond in a controlled environment with low natural production and up to 12.89 % compared to untreated cereals in ponds with relatively high natural production of appropriate conditions in Třeboň area. Tests were done at K3 to K4 ages of carp with normal stocking densities and supplementary feeding intensity. Evaluating the economic efficiency of heat-treated cereal respected the change in protein and polysaccharide content, due to the reduced water content, which resulted in an increase of the original content of protein and polysaccharide in the order of a few percent. The costs of the technological adjustments, mechanical or thermal were in the order of tens of crowns for 1 q (1 q = 100 kg) of cereals. Technological modifications by pressing or crushing were more3 expensive by about 10 to 15 CZK / q; the heat treatment costs were about 20 to 30 CZK / q.

Třeboň Fisheries currently consumes 100 t of heat-treated cereals annually. Increasing the growth by 10–12% can cause the financial effect of 90–100000 CZK per year. The extension of the use of heat-treated feed can save feed costs in the order of several hundred thousand CZK

Reducing the load of ponds with indigestible and non-absorbable nutrients, especially phosphorus (total phosphorus, TP) is an effect whose financial impact is not precisely quantifiable. Annually, it would be possible to expect a direct saving of tens of kilograms of the TP in the case of Třeboň Fisheries according to the above data, which is released into the Lužnice basin. A further reduction the TP input into the aquatic environment is due to the higher digestibility and utilisation of the heat-treated cereals to considerable parts of fish stocks.

6. The application of technology in production

The use of pressed, heat-treated, grinded cereals or a combination of heat-treatment and pressing is utilized in bigger companies for pond aquaculture. In comparison with granular feed, processed cereals are attractive because of their economic availability, a significantly higher stability in water (excluding grinded cereals) and have an almost equivalent level of digestibility of individual components (proteins nitrogen-free extracts, digestible energy, etc.). This method of treatment is generally available for most aquaculture companies as the feed could be purchased from production and supply enterprises also involved in the sale and distribution of feed for livestock.

The Method of using modified cereals increases the conditions of effective supplementary feeding for a wider age range of carp. While the unmodified cereal feeds are given mostly to carp in breeding ages K_2 to K_3 and K_3 to K_4; the modified cereals, can be used for K_r to K_1 and K_2 for a considerable part of the growing season with very beneficial results due to physiological availability of nutrients.

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CHAPTER 5

TEXTURE PROPERTIES OF COMMON CARP CULTURED FROM DIFFERENT SYSTEM

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TEXTURE PROPERTIES OF COMMON CARP CULTURED FROM DIFFERENT SYSTEM

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Abstract

Common carp is one of the most widely cultivated fish species in Central and Eastern Europe. Nowadays, with the quality of fish flesh having a more significant role in consumer demands, textural properties namely hardness, cohesiveness, springiness and gumminess play a vital role in developing consumer perceptions and maintaining a high demand. Fish with a mean body mass of 1501 ± 127 g and 891 ± 74 g, and a fat content of 4.3 ± 1.2% and 2.3 ± 0.8% were harvested from semi-intensive (SIS) and extensive (ES) systems respectively. The textural properties of the fillets were measured after being stored at 2 °C for a period of 24h. No significant differences were observed in the cohesiveness values ($P > 0.05$) between the different culture systems. However, significant differences ($P < 0.05$) were observed in the following other textual parameters measured and calculated. Fish from SIS and ES had a mean hardness value of 199.62 ± 52.08 N and 126.10 ± 29.90 N, respectively. Springiness values were 0.72 ± 0.07 and 0.62 ± 0.03 for ES and SIS, respectively. The value of chewiness for ES was 5807.51 ± 1043.25 and 2936.13 ± 749.35 for SIS. This study shows that the textural properties, especially the hardness of common carp fillets are therefore particularly dependent on the culture system used. Feeding strategies as well as general pond management is therefore of critical importance to enhance the textural properties of common carp fillets and meet consumer demands.

Keywords: *Cyprinus carpio, extensive culture system, fillet, hardness, texture analysis*

Introduction

Common carp (*Cyprinus carpio* L.) is one of the most important and widely cultivated species of freshwater fish, cultivated in a variety of climates, in ponds with various levels of management and culture systems (e.g. Kestemont, 1995; Fallahi et al., 2013) as one of the first domesticated fish (Balon, 1995), with a total global production of ~ 3.2 million tons in 2010 Food and Agriculture Organisation (FAO, 2012). Much of the production takes place in Central Europe, especially. Common carp is also by far the best choice for utilizing pond resources under the temperate climate of Central and Eastern Europe (Woynarovich, 2011).

As the quality of products available increases due to consumers having a bigger input both directly and indirectly in the production of goods, suppliers are more easily able to analyse the specific preferences of consumers (Rasmussen et al., 2013). Through this analysis, suppliers can alter products or make changes in the production or processing chain in order to develop a product which is favourable to the consumer. Consumer preferences may differ considerably between people from different regions, gender and ethnicity along with many other differences and can lead to suppliers targeting these different groups with different products (Lee et al., 2013; Söderberg, 2013). In fish products, consumers are particularly interested in the appearance, taste, texture, odour and fat content of the product which leads to a perception of the quality of the fish (Fauconneau et al., 1995; Rasmussen et al., 2013). Fresh fish with a fine, firm texture is widely favoured and can be measured in a number of ways including sensory measurements and by using mechanical instruments (Coppes et al., 2002).

Many studies have been conducted to correlate sensory analysis with mechanical testing and compare the different analysis methods. Some believe that texture is only quantifiable when viewed as a sensory property, and human sensory testing methodology is implemented to measure it (Szczesniak, 1998). Sensory analysis has always had a role to play in the production process of fish products, and many reviews, experiments and results have been published concerning it (e.g. Connell and Shewan, 1980; Chamberlain et al., 1993; Khanipour and Mizarkin, 2013).

Texture profile analysis is generated then used to quantify a number of textural parameters that correlate well with results from sensory evaluation. Textural properties such as hardness and cohesiveness can be measured and provide insight into the textual quality of the fish, allowing us to calculate other properties such as springiness and chewiness. The aim of this study was to evaluate two of the main quality parameters, namely fat content and textural properties in relation to two different carp culture systems.

Material and Methods

Fish sample

Four year-old common carp from extensive (ES) culture system (low stocking density with no supplemental feeding) and semi-intensive (SIS) system (supplementary feeding with cereals) were harvested in the July 2013 (~ middle of the growing season) from fisheries Třeboň a.s. (Czech Republic, Central Europe). After harvesting six fish were randomly chosen from both groups of different culture system and slaughtered in slaughtering room of the Faculty of Fisheries and Protection of Waters in České Budějovice, Czech Republic. At the time of slaughter the basic parameters was measured and calculated in each fish. Body length (BL) was measured using a roller (mm), body weight (BW) was measured using a digital weight (KERN, PFB 6000-1, Germany, ± 0.1g); thickness of fillet (TF) was measured using a digital calliper (16 EWR-NA, Germany); Fillet yield (%) was calculated: 100 * weight fillet / final body weight; and Fulton coefficient was calculated according to formulae: (FC) = m / BL^3 * 100, where m is weigh (g) and BL is body length in cm. The fish were filleted by hand by one person to ensure consistency.

Textural measurement

The trimmed fillets were immediately wrapped in plastic bags and transferred to refrigerator (at 2 °C). After 24 hours the sample were cut from dorsal part of fillet below the dorsal fin for textural measurement using a TPA-meter (TA.XTPlus, Stable Micro Systems, Godalming, England) with respect to the lateral line of the fish body. A compression plate 75 mm (P/75) was selected and setting were follow: Pre-test Speed 5mm.s, Test speed 2mm.s until the fillet was compressed to 50% of its original thickness. Data collection and calculation were carried namely – hardness (N) which is defined as the maximum force detected during the first compression.

Cohesiveness was measured as the ratio of the positive force during the second compression to the positive force during the first compression. Springiness is described as the ratio of the time or distance from the start of the second area to the second probe reversal over the distance, or the time between the start of the first area and the first probe reversal. Chewiness is defined and calculated as hardness × cohesiveness × springiness – these three are dimensionless.

Fat content and pH

Whole fillets with skin were minced in a table cutter to ensure that all edible parts were represented in the sample analysed. Lipid extraction was performed according to Hara and Radin (1978) with slight modifications described in Zajic et al. (2013). pH was measured by blending 10g of homogenised fish fillet and 20 ml of distilled water, using a digital pH meter with thermometer Testo 206 (Testo AG Germany) For homogenization of fish sample and distilled water was used digital ultra-turrax 20 000 rpm, T18 Basic (IKA, Germany). The mean value of pH was 6.42 ± 0.01 and temperature was 25.7 ± 0.1 °C for fish from ES and for fish from SIS was mean value of pH 6.43 ± 0.01 and temperature 25.7 ± 0.1 °C, respectively.

Statistical analysis

Data were subjected to one-way ANOVA followed by Tukey's test ($P < 0.05$). All data were analysed using STATISTICA 10.0 for Windows. All data were checked for normality and homogeneity of variance before analysis.

Results

Fish sample

The mean values and standard deviation of parameters which were measured, calculated and estimated in each fish (Table 1). For values such as BL, BW, fillet yield and TF were significant ($P < 0.05$) statistic differences between ES and SIS. But there was no significant difference ($P > 0.05$) in mean values of FC between extensive and semi-intensive carp culture system.

Table 1. *Parameters which were measured, calculated and estimated at the time of slaughter: body length (BL), body weight (BW), Fulton's coefficient (FC), filet yield and thickness of fillet (TF).*

Culture system	BL (mm)	BW (g)	FC	Filet yield (%)	TF (mm)
ES	313 ± 8.2^{a}	891± 74^{a}	2.89 ± 0.21	43.5 ± 0.50^{a}	16.21 ± 1.11^{a}
SIS	365 ± 7.78^{b}	1501 ± 127^{b}	3.06 ± 0.01	46.24 ± 1.55^{b}	26.23 ± 0.39^{b}

* Data are expressed as means ± SD (n = 6)
Different script letters characterize significant differences in each column for different carp culture system ($P < 0.05$).

The percentage of fat content in fillet of all fish from ES and SIS is showed in Fig. 1. The fish from ES had a significantly ($P < 0.05$) lower value of fat content (2.3 ± 0.8 %) then the group of fish form SIS (4.3 ± 1.2 %). The mean values of hardness for fish from ES and SIS were 199.62 ± 52.08 N and 126.10 ± 29.90 N, respectively (Fig. 2). The mean values for cohesiveness and springiness shows Fig. 3. There was not observed significant difference ($P > 0.05$) in cohesiveness between ES and SIS. The mean values for ES and SIS were nearly the same 0.39 ± 0.10 and 0.37 ± 0.05, respectively (Fig. 3). But there was a significant difference

(P < 0.05) in springiness. The mean values were 0.72 ± 0.07 and 0.62 ± 0.03 for ES and SIS systems (Fig. 3). Figure 4 shows significant differences (P < 0.05) between ES and SIS in the chewiness. The mean value of chewiness for ES was 5807.51 ± 1043.25 and 2936.13 ± 749.35 for SIS, respectively.

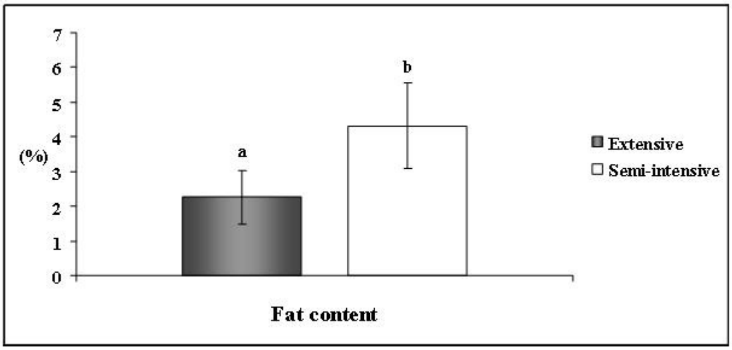

Figure 1. *Effect of carp culture system on fat content (%).*
Note: Different letters indicate significant differences at P < 0.05 (Tukey's post hoc test).

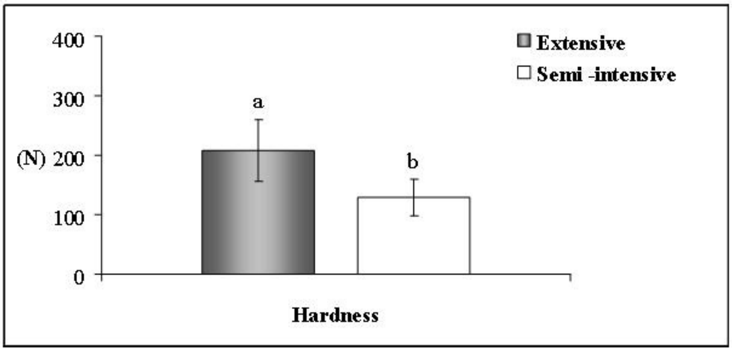

Figure 2. *Effect of carp culture system on hardness.*
Note: Different letters indicate significant differences at P < 0.05 (Tukey's post hoc test).

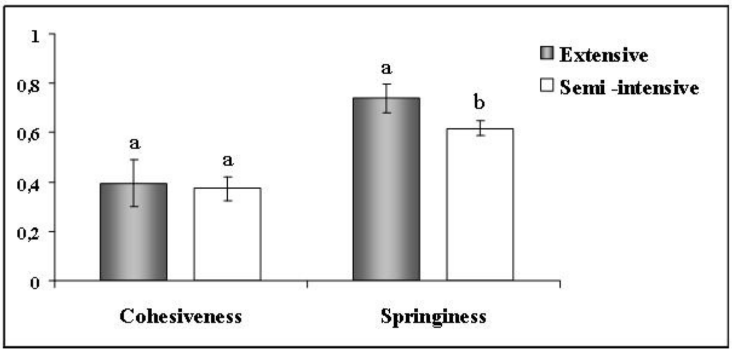

Figure 3. *Effect of carp culture system on cohesiveness and springiness.*
Note: Different letters indicate significant differences at P < 0.05 (Tukey's post hoc test).

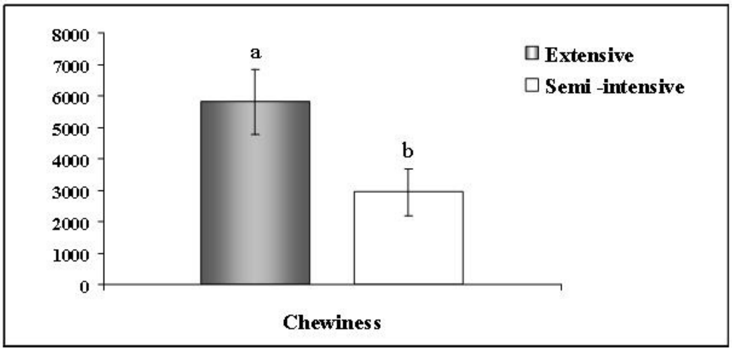

Figure 4. *Effect of carp culture system on chewiness.*
Note: Different letters indicate significant differences at P < 0.05 (Tukey's post hoc test).

Discussion

There is a wide range of textural properties hardness, cohesiveness, springiness, gumminess, chewiness and some authors moreover recognized juiciness (Szczesniak, 1963) and for example greasiness (Brandt et al., 1963) and so on of food as the property of the texture. Due to the non-uniform nature of fish fillets, variations at different areas of the fish body (e.g. Botta, 1991; Reid and Durance, 1992) and sampling technique classifying the texture can be a difficult task (Coppes et al., 2002). There are many studies deal with textural properties of fish or texture parameters of fish using different methods of sampling and wide variety of texture analyzers (probes) to measure texture properties with different results (e.g. Connell and Shewan, 1980; Chamberlain et al., 1993; Dilip et al., 2007; Sigurgisladottir et al., 1999). However less information is published about texture parameters at different areas of the fillets (Azam et al., 1989; Botta, 1991; Dilip et al., 2007) and different culture system of fish (Stejskal et al., 2011). According to Dilip et al. (2007) sampling technique is the major relevant factor for the integrated results of the texture properties. Moreover Dilip et al. (2007) concluded that the most serious part for practical application is below the dorsal fin. This could be an important factor for other studies which should be investigated.

The textural properties which are important actors for consumers because they prefer firm and elastic fish flesh (Rasmusen, 2001). The results of the textural properties, namely hardness, springiness and chewiness (Fig. 2, Fig. 3 and Fig. 4) of raw carp fillets showed significant differences between ES and SIS. A significantly higher value of hardness had a fish from ES was observed. Also other two parameters, springiness and chewiness, had a significantly higher values of carps from ES. These results are in accordance with other studies dealt with texture properties of fish such as salmon (*Salmo salar*), sea bass (*Dicentrachus labrax)* and Eurasian pikeperch (*Perca fluviatilis*) (Periagó et al., 2005; Johnston et al., 2006; Veiseth-Kent et al., 2010; Stejskal et al., 2011). On the other hand, no significant difference was found in cohesiveness between ES and SIS (Fig. 3). This is in contrast with results published by Stejskal et al. (2011), who reported also significant difference in cohesiveness between raw fillet of Eurasian perch farmed in extensive pond-based system in polyculture with carp and raw fillet of Eurasian perch farmed in intensive system in recirculation system.

To summarise, there were significant differences in almost textural parameters (except cohesiveness), we could say, that culture system of common carp have an influence on textural properties. But there are some studies which reported about the culture system and influence of the fat content in fish fillet on textural properties. Anderssen et al. (1997) reported that rainbow trout (*Oncorhynchus mykiss)* with higher fat content showed less resistance against compression which leads to softer consistency of fish meat. Also Orban et al. (1997) reported that fillets from extensively farmed sea bream (*Sparus aurata*) had significantly higher texture parameters which may be due to the less fat content. This is accordance with present study, because our result shows, carps from ES had a significantly lower fat content then carps from SIS. It could be the reason why fish from EC also have significantly higher textural parameters – except cohesiveness.

Post-mortem changes occur in fish with a number of different processes altering the texture of the product reaching the consumer. The different processes occurring can lead to glycolysis, rigor mortis, change in toughness, and gaping of the flesh (Coppes et al., 2002). Greaser and Pearson (1999) reported that the time for complete process of rigor mortis in fish is 5–24 h. The pH level of fish flesh after harvesting can be considered to be the greatest factor influencing the texture of the product at this stage (Dunajski, 1980; Love et al., 1974). As the pH drops, the toughness of fish flesh generally increases.

Textural properties of fish flesh are influenced by an extensive range of factors and are often linked to other parameters of the flesh such as odour and taste. A number of testing methods are available for testing fish at different raw stages, and offer insight into a variety of parameters linked to texture. These tests play an important role in the processing and product development industries. We are able to manipulate the textural properties of a product to a certain degree at different stages of the production or processing chain.

Culture system of common carp has an influence on textural properties of common carp fillets measured by Texture Analyzer TA.XT*Plus*. The fish from extensive culture system had lower fat content then the other group of fish. Feeding strategies as well as general pond management is therefore of critical importance to enhance the textural properties of common carp fillets as well as fat content and meet consumer demands. As consumer preferences in respective to fat content and softness have shown a regional variability, the used culture system and resulting quality should be indicated at the market. Because of the non-uniform of the carp fillet, the most serious part for practical application of measurement textural properties of common carp is below the dorsal fin with respect to the lateral line of the fish body. Further research should be evaluated for textural properties of common carp from different level of management and culture systems.

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CHAPTER 6

GENERAL DISCUSSION
ENGLISH SUMMARY
CZECH SUMMARY
ACKNOWLEDGEMENTS
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TRAINING AND SUPERVISION PLAN DURING STUDY
CURRICULUM VITAE

GENERAL DISCUSSION

Besides as feed for fish, cereals are mainly utilized for animal feed as well as human nutrition, and they are an essential raw component for the production of "bio ethanol" (Nazimek and Niećko, 2010). That could be the possible reasons for the increasing price of cereals. Therefore, cereals represent one of the most important economic factors in carp pond aquaculture. Feeds represent about one third of the total costs within market carp farming. The tendency of all fishery companies is naturally to reduce these costs as much as possible. Our hypothesis was that the reduction of costs within the carp farming could be realized by using a suitable treatment of cereals in order to increase the nutritional value, acceptability and especially digestibility of the feeds and thus increase fish growth, body weight gain of the fish and harvesting yield of fish from the ponds. Constituent secondary aim of this treatment is to preserve or enhance the quality of fish product. Beside this we assume that a side effect of increased acceptability and digestability could result in lower proportions of undigested feed and feed metabolites and thereby improve water quality and reduce eutrophication of the ponds.

Statistical growth model

The overall aim of the first study was to develop a growth model and an essay to estimate the production efficiency of pressed cereals (wheat, barley, rye and triticale) compared to whole cereals. In addition we aimed to determine the best estimating fitted model to calculate the growth of common carp during the production seasons, which are the last four seasons respectively. Some earlier studies deal already with growth models (e.g. Yamada, 2002; Jobling, 2003; Akamine, 2009). But these very general models could be used for growth prediction for all fish species while we aimed to statistically estimate growth for carp in the fourth growing production season. Such a specific modell could be much more precise than the existing general models and could hence be of better use for the fish farmers. We developed five different fitted models which differed in using several different mixed linear models that can be expressed in the matrix form $y_i = X_i\beta + Z_i b_i + \varepsilon_i$ (Laird and Ware, 1982) with an assumption vector of random effect $b_i \sim N(0,\Psi)$ and a within-group error $\varepsilon_i \sim N(0,\delta^2\Lambda_i)$.

The simplest model M1 was estimated as a linear mixed model with a random intercept. Model M2 was estimated as a linear mixed model with a random slope and model M3 was a linear mixed model with a random intercept and slope. The fitted model M4 is written as model M3 with a power variance function, where the error variance was modelled as $Var(\varepsilon_{ij}) = \delta^2|t_{ij}|^{2\delta_{ij}}$ and with one covariate function $g(t_{ij},\delta_{ij}) = |t_{ij}|^{2\delta_{ij}}$, and M5 was written as model M4 with a power variance function, with the error variance modelled as $Var(\varepsilon_{ij}) = \delta^2|t_{ij}|^{2\delta_{s_{ij}}}$ and one covariate function $g(t_{ij},\delta_{ij}) = |t_{ij}|^{2\delta_{s_{ij}}}$. The model M5 takes heterogeneous errors with respect to differing strata, e.g. different diet, into account. In order to evaluate which model would predict the fish growth most accurate we used a comparison test according to Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) and the likelihood ratio test. According to the results the most suitable model to calculate growth of carp was M5. The suitability of the chosen model is also confirmed by the results of the study for showing a higher value of likehood ratio test and lower (AIC) and (BIC) compared to the other models (Chapter 2).

Production efficiency of technologically modified cereals

The specific production efficiency of cereals technologically modified in various ways was evaluated in the first three manuscripts (Chapter 2, 3 and 4). The role of natural feed in the ponds is well known and essential for a better utilization of the supplemental feed in semi-intensive system. For example the skeletons of copepods and cladocerans are used by the carps for the mechanical crushing of feed material in the digestive organs (Jancarik, 1964; Strumbauer and Hofer, 1986). Furthermore it was found that a high proportion of proteolytic enzymes from the natural feed had a positive effect on the digestion process in the fish (Dabrowski and Glogowski, 1977). This was confirmed by our results. When a higher amount of zooplankton, especially cladocerans and copepods (> 0.7 mm) was observed in the ponds, the carps had an increased weight gain (Chapter 4).

On the other hand carp weight gain depends also highly on water quality; mainly temperature, dissolved oxygen and pH (Kestemont, 1995; Horváth et al., 2002; Flajšhans and Hulata, 2007). The digestive system of fish is effectively adapted to ambient temperature and the water temperature has a significant influence on fish metabolism because carp are poikilotherm organism. According to Schwarz (1997) digestion in common carp is most effective at water temperatures around 23–25 °C. When the water temperature decreases from 25 to 18 °C, digestion in common carp is significantly reduced (Yamamoto et al., 2001). According to Jirásek et al. (2005) the optimal oxygen saturation should be between 70–75% for optimal growth of carp in ponds. During our experiments we observed suboptimal values of temperature with a mean value around 21 °C and a suboptimal saturation of oxygen around 70%. Besides this no extreme deflection of temperature and oxygen was detected during the experiment. The observed meanvalue of pH was 7 which is in accordance with the recommendations for optimal values between 6.5–8.5 for carp, described by Horváth et al. (2002).

The results from our first study were confirmed by the results of the second study. Already earlier mechanical modified (pressed and grinded) triticale *(Triticosecale sp.* A. Camus, 1927) has been shown to be suitable for supplementation feeding of common carp (Urbánek et al., 2010). Triticale is a cereal designed to incorporate the functionality and high yield of wheat (*Triticum spp.* L) and durability of rye (*Secale cereale* L) (McGoverin et al., 2011). Our results indicated that mechanically processed triticale was associated with a higher IWG and SGR compared to carp fed with whole grain or zooplankton diet only. Also Pryzbyl and Mazurkiewitz (2004) and Przbyl et al. (1994) reported a high effectiveness of feed containing modified triticale in intensive production of carp (initial weight 200 g ± 10 g) in ponds, but found no significant differences in weight gain, SGR, or FCR between different cereal types.

In our studies, the values of FCR was significantly lower (14%) in pressed triticale compared to whole grain and about 9% in grounded triticale compared to whole grain, respectively. However we did not observe a significant difference in Fulton`s condition factor (FC), which is an indicator of "well-being" or "plumness" of fish. According to Bauer and Schlott (2009) the value of FC for healthy well-fed carp was in the range of 1.9–2.2. Comparingly in our studies the FC value was between 3.0–3.5. This difference is caused by the fact, that we used body length (BL) which is measured in a fish from the tip of the snout to the posterior end of the last vertebra for our calculations, while Bauer and Schlott (2009) used the total length (TL), which was measured as the length from the tip of the snout to the tip of the longer lobe of caudal fin for their calculations. After recalculation our values were comparable to those calculated from Bauer and Schlott (2009). Our results agreed with other studies, which also used the BL for calculation of FC (e. g. Gela et al., 2003; Urbánek et al., 2010; Zajic et al., 2013) and the FC values in these studies were similar to ours (2.9–3.7; 3.2–3.7 and 3.3–3.7, respectively). Moreover, Gela et al. (2003) described significant differences in FC values between crossbreds of common carp and between sexes. We found significant differences between supplementary fed groups of carp and carp only on natural feed. Our result are in line with Zajic et al. (2013) who also concluded that carp on a natural diet had a lower FC value compared to carp supplemented with cereal or pellets. Based on our results, a FC value higher than 3 might be concluded to be an indicator for healthy well-fed carp.

Improvement of the water quality

A very important component in pond aquaculture is to minimize a pollution of pond during the production of carp. At the same time as the world aquaculture has rapidly developed and has become more intensified, also carp pond aquaculture has rapidly developed and intensified. This intensification of carp culture and pond management (feeding, manuring, liming, etc.) and other influences such as human settlements and agricultural activities led to a gradually eutrophisation of the aquatic ecosystem (Pechar, 2000; Potužák et al., 2007) and the ponds respectively. The owners of the ponds as well as the fish farmers have hence to be aware of various factors related to their business. They have not only to assure and maintain the welfare of the fish, and deal with economy aspects but they must also consider the pond water quality (Dulic et al., 2010; Máchová et al., 2010). Water quality may be strongly influenced by the degree of intensification and fish biomass in the pond. Due to a higher density of carp an increased turbidity and nutrient concentration, especially phosphorus occurs (Driver et al., 2005; Chumchal et al., 2005). With the world concern to reduce water pollution, also the companies dealing with the production of fish feed tried to find methods to reduce especially the phosphorus excretion in fish (Rodehutscord et al., 2000). Breeding of market carp should fulfil the purpose of the production of food, while respecting the laws in force to protect the environment by using the available scientific and technical knowledge. We know that a suitable treatment of cereals can lead to better utilization of the feed and thereby reduce the leakage of phosphorus from the feed into the water (Hlaváč et al., 2014). The certified technology summarizes new findings related to the efficiency of traditionally treated animal feeds namely cereals, which has been applied successfully in the feeding of carp. The paper III describes a technique of feeding and showed to reduce the impact of carp feed on the balance of phosphorus in water. Phosphorus is known to be the main element of eutrophication. The used technique improved the feed efficiency and monitoring feed efficiency is an important factor both in controlling water quality and the welfare of farmed fish.

The application of artificial feeds (in our case cereals) in semi-intensive production systems of carp farming increases the yield of the ponds as the fish are capable of retaining nitrogen and phosphorus better. The total protein in cereals varies depending on the species and ranges between 7 to 15% (Füllner et al., 2000). The amount of total phosphorus in different cereals species ranges between 2.9–3.7 $g.kg^{-1}$ (Hlaváč et al., 2014). In paper III we detected 3.15 $g.kg^{-1}$ TP in the whole grains and 3.25 $g.kg^{-1}$ TP in the heat treated cereals respectively.

To calculate the phosphorus balance, it is necessary to know the input of this element by the supplementary feed. A method to assess the nutrient balance was described by Duras and Potužák (2012). Our own data suggested that the use of heat modified cereals, improves the feed efficiency in carp ponds due to a higher digestibility. This simultaneously increased the yield of the fish biomass and reduced the the FCR about 13% compared to unmodified grain. With the better utilization of the feed also the nutrient uptake by the carp increased. This reduced the amount of undigested or poorly digested food and subsequently the total phosphorus load in the water. According to Siddiqui and Harbi (1999), Jahan et al. (2002) and Schneider et al. (2005) the utilization of phosphorus in fish is between 15–56% from the feed while the rest (68–86%) is excreted (Avnimelech and Lacher, 1979; Crab et al., 2007; Rahman et al., 2008). On the other hand there might be some unexplored sources of phosphorus as input or output in the pond ecosystem. According to some studies in open ecosystems there might be potential unexplained impacts of sediment, bioturbation of fish, fallout, insects, dust and rainfall (Cole et al., 1990; Newman, 1995; Kopáček et al., 1997; Holas et al., 1999; Matsuzaki et al., 2007). Moreover even in recirculation systems, which are closed systems, generally 15–25% of the nutrient balance remains unexplained (Verdegem, 2007) and thus the balance of nutrients is very difficult to estimate. In spite of this, the application of modified cereals as artificial feed in semi-intensive carp farming showed to reduce the concentrations of phosphorus in water compared to the use of untreated cereals.

Effects of production system on quality of fish

The increasing demands for fish of the growing world population could be met by an increased production of fish in aquaculture. However it is essential to produce a suitable quality of fish and fish products which are acceptable to the consumer's expectations and tastes. For the cyprinids general flesh quality is described in Steffens et al. (1992). Apart from producing a variety of products we also need to improve the methods of marketing and promoting of products as carp.

One of the appreciated products is carp fillet. Filleting is a part of slaughtering processing of carp. Usually carps are filleted by hand by a trained expert to minimize losses during the slaughtering process. The fillet yield of market-size common carp from Central Europe usually varies from 34.0 to 41.1% of the original body weight for fillet with skin (Cibert et al., 1999; Kocour et al., 2007; Bauer and Schlott, 2009) and from 31.4 to 38.7% for skinless fillets (Oberle et al., 1997; Gela et al., 2003; Kocour et al., 2007). This is about 10% lower compared to salmonids (e.g. Einen et al., 1998). The fillet yield depends on the body size and the body weight of the fish respectively. The body weight is depended on the pond management. Our results confirmed that the fillet yield was significantly higher ($P < 0.05$) in fish supplementally fed with modified and unmodified cereals compared to natural fed carps. But between modified and unmodified cereals no significant difference ($p > 0.05$) was found. Moreover we found a positive correlation (Spearman's ρ test; $\rho = 0.59$) between fillet yield and weight. This is in accordance with Kocour et al. (2007) who also found positive correlation ($r2 = 0.46$) between fillet yield and body weight in carp.

In some other studies the relationship between body weight and fillet yield in different fish species showed varying correlations. For example, Rutten et al. (2005) found a correlation (0.48) between fillet yield and body weight in Nile tilapia (*Oreochromis nioloticus* L.). Similary Kause et al. (2007) described a positive correlation between fillet yield and body weight in rainbow trout (*Oncorhynchus mykiss*). However, these results are in contrast with Bauer and Schlott (2009) who reported no correlation (-0.16) between body weight and fillet yield of carp. His results are supported by Cibert et al. (1999) who also reported no correlation (0.06) between fillet yield and body weight of carp. This variable results might be due to the wide range of weight of carps (790–2310 g) as well as wide range of fillet yield (27.1–41.9%) present in study Cibert et al. (1999).

The consumers of today have a larger variety of fish products and their possibility to choose the product which complies with their perceptions causes producers to invest in product development to secure sales. There is an increased competition in the market as producers and processors strive to supply a product most desired by consumers. In fish products, consumers are particularly interested in the appearance, taste, texture and odour of the product which leads to a perception of the quality of the fish (Rasmussen et al., 2013). Scientifically the quality of fish can be estimated by different ways including sensory evaluation and by the use of mechanical instruments or methods, as for example the texture profile analysis (TPA).

The textural properties are important factors for consumers because most consumers prefer firm and elastic fish flesh (Rasmusen, 2001). The sampling technique is the major relevant factor influencing the texture parameters (Dilip et al., 2007). However also different culture systems could be result in a variation of the quality and the texture parameters of fish. In our study we show that various texture parameters, namely hardness, cohesiveness, springiness and chewiness are significantly influenced by different culture systems. The textural parameters were significantly higher in fish from the extensive system than in fish from the semi-intensive system. Already earlier studies dealing with the relationship of texture parameters and the origin of the fish have been carried out for other species. For example Johnston et al. (2006) showed that wild salmon (*Salmo salar*) had a firmer texture than farmed fish. Also Periago et al. (2005) reported that wild sea bass (*Dicentrachus labrax*) had significantly higher textural parameters than farmed sea bass. Stejskal et al. (2011) compared the effects of two different rearing systems of farmed Eurasian perch (*Perca fluviatilis* L.) on textural parameters of raw fillet. His results elucidated that Eurasian perch from an extensive system had significantly higher textural parameters compare to intensively cultured fish. Moreover Stejskal et al. (2011) found a significant difference in cohesiveness which is in contrast with our results on carp. In line with our results, Vácha et al. (2013) reported that cyprinid fish – tench (*Tinca tinca* L.) from an extensive system had significantly higher textural parameters than tech from an intensive system. Moreover Vácha et al. (2013) found a significant difference in textural parameters between male and female tench. This confirms that not only different culture system have an influence on the textural parameters but also the gender of the fish. Additional factors which might have an influence on textural parameters are the pH value, temperature, fish size and thickness of fillet (Veland and Torrissen, 1999). In our study carps from the extensive system had a significant ($P < 0.05$) lower fillet thickness and significantly higher textural parameters compared to carp from the semi-intensive systems. This could also be the reason why the fish from the extensive system had significantly higher textural parameters. Similarly Veland and Torrissen (1999) found that the thickness of fillet of Atlantic salmon fillet had a very significant effect of the texture parameters.

Beside texture, the fat content is one of the main factors affecting fish flesh quality, especially as fat content does also influence the texture of fish flesh. The total fat content in the fish increases with size of common carp (Viola et al. 1988a; D´Mello et al., 1989). Our results indicate that carp with a lower fat content has significantly higher textural parameters, especially hardness. This is in line with some other studies. For example Andersen et al. (1997) reported that rainbow trout (*Oncorhynchus mykiss)* with higher fat content exhibited a lower resistance against compression which results in a softer consistency of the fish flesh. Similarly Orban et al. (1997) described that fillets from extensively farmed sea bream (*Sparus aurata*) had significantly higher texture parameters most possibly due to the lower fat content.

Final fat content of the fish will also vary according to the feed used and the amount of feed supplemented and there is a strong influence of pond management and the diet (Fauconneau et al., 1995; Anderson and De Silva, 2003; Zajic, 2013). In general, fish supplemented with cereals produce fish with a higher fat content compared to fish depending only on natural feed (zooplankton and zoobenthos) (Urbánek et al., 2010; Zajic et al., 2013). In line with this we found significantly differences among the fish groups supplemented with different treated cereals and natural feed only. The significantly lowest value of fat content was found in the control group which was feeding only on natural feed. Similarly Urbánek et al. (2010) found significant higher content of fat in fish supplementary fed compared to fish without supplementation.

Nevertheless, the mean value of total fat should not be higher than 10 %. The critical fat content for a good quality of fish flesh is 10 %. A higher fat content (above 10%) resulted in a negative effect on sensory properties of carp flesh which subsequently will have negative impact on consumer's demand (Dr. Oberle, personal communication). In opposite a too low fat content could result in a tough structure and increased texture parameters. This relationship is also proven in our fourth study, were carp from an extensive system with a lower fat content showed higher texture parameters compared to carp from semi-intensive system (Chapter 5).

The fat content of the carp in our study was below the critical value of 10% and the fish was considered as a good pond aquaculture product with a high quality of carp flesh. The strategy and the feedings techniques applied may lead to better quality of carp flesh. The carps supplementary fed by pressed triticale had the highest mean value of fat contet (7.2%) while carp fed by grinded triticale had a mean value of 6.4%. Thus, it can be considered that carp supplementary fed by mechanically modified cereals, have a good quality in respect to a favourable fat content of the fillet.

Other factors affecting fat content are the genetic origin of the carp and age of the fish. For example Kocour et al. (2007) found a high heritability (> 0.5) for fillet fat percentage in common carp, which presents interesting prospects for selective breeding. However, also a variability of fat content is observed in carp of the same age (e.g. Kocour et al., 2007; Bauer and Schlott, 2009).

In generally it can be estimated that many factors might have an influence on quality of fish flesh fillet especially on the texture parameters. In our study we found differences between extensive system and semi-intensive system. The production system and feeding seem to be very important factors which might have an affect on texture. Nevertheless, there is only little information about the role of fish feed and nutrition on the texture parameters of fish fillets. For the future it could be important to investigate, if different treatments of cereal as well as different pond management systems have an influence on texture parameters.

General conclusions

A semi-intensive farming system results in an increased production. Processing cereals resulted in a decreased feed conversion and hence a more economical production. At the same time the processing of the feed resulted in a better nutrient uptake by the fish and subsequently to a lower release of phosphorus to the water ecosystem. Fish from semi intensive rearing systems exhibited more tender texture properties and hence should be more attractive to the consumers. From our studies we can conclude that a semi-intensive rearing system with the utilization of technological modified cereals will result both in increased economical and sustainable production of carp as well as to a higher and more consistent and predictable quality of common carp flesh.

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ENGLISH SUMMARY

Production efficiency of technological modified cereals in market carp farming

Jan Másílko

Common carp (*Cyprinus carpio* L.) is one of the most important cultivated fish species over the world. In the Czech Republic, the production of carps has a long tradition and a non-interchangeable appearance in the cultural landscape by pond aquaculture farming. The production is mainly executed in semi-intensive systems, were a combination of natural feed with additional feeding of cereals is applied. Mostly all available cereals are used for supplemental feeding. Due to that the need of cereals represents one of the most important economic factors in the business. It is estimated that these cost can be around 30–35% of total costs within the carp farming.

A possibility to reduce these costs is to increase the production efficiency of the feed, in our case cereals, using a suitable technological pre-treatment. The chosen technological treatment should be simple, cheap and easy available for thecommon practice in fishery. The technological treatment of cereals may lead to better economical situation of the fish companies due to a higher nutritional value, acceptability and especially digestibility and thus increase body weight gain of the fish. Due to a suitable treatment carp may better utilise and digest the cereals. Thus it may also lead to a reduced environmental burden of indigestible and non-utilise nutrients (metabolites), especially total phosphorus (TP).

The objective of first study was to evaluate the best model for the growth of the carp during the last (fourth) growing season. Different modified (pressed) cereals and different non-pressed cereals were used under semi-intensive pond farming conditions for supplementary feeding. For the evaluation, we employed five models designated M1 – a linear mixed model with a random intercept; M2 – a linear mixed model with a random slope; M3 – a linear mixed model with a random intercept and slope; M4 – written as model M3 with a power variance function, where the error variance was modelled and M5 – written as model M4 with a power variance function, with a different model of error variance. From these five models, model M5 showed to be best for the prediction of growth of carp. The sub-constituent part of this study was to determine the efficiency of the mechanical modified cereals. Our results show that the pressed cereals resulted in a better growth and a lower food conversion ratio (FCR) of carp as well as a lower variation final weight of carps.

The second study describes the efficiency of mechanical modified cereals, especially pressed and ground triticale, compared to whole grains in common carp diet on the growth, feed conversion, fat content and fillet yield of market size carp grown in ponds. Our results indicate that carp is able to better utilize mechanically modified cereals. Fish fed modified cereals reached a significant higher individual weight gain and a significant lower FCR compared to carp feeding on whole grain only was observed. This will in turn lead to reduced total costs within the carp farming. However, the influence of the mechanical treatment of cereals on the FC (Fulton´s coefficient) and the filet yield did not differ significant compared to whole grain at the same level of pond management strategy.

The possible impact on the environment of different treatments of cereals (heat treatment, pressed, grinded, heat treatment and pressed) is described in the third study. The treatments of cereals, especially a heat treatment, showed to reduce the load of ponds with indigestible and non-utilisable nutrients, especially total phosphorus (TP). This effect is caused by the better utilization of the modified cereal by the carp. This is an effect whichs financial impact

is not exactly quantifiable. However, according to our data we estimated it would be possible to significantly reduce the leakage of TP into the pond systems and subsequently the ground water.

Nowadays, with the quality of fish flesh having a more significant role in consumer demands, textural properties play a vital role in developing consumer perceptions and maintaining a high demand. The textural properties (namely hardness, cohesiveness, springiness and gumminess) of common carp flesh fillet fed different diets, were measured and calculated in study 4. Fish from a semi-intensive system were compared to fish from an extensive system. This study shows that the textural properties, especially the hardness of common carp fillets are dependent on the culture system used. Carp from the extensive culture system had a statistically ($P < 0.05$) higher mean value of fat content and conversely a statistically ($P < 0.05$) more tender muscle structure. Feeding strategies as well as general pond management is therefore of critical importance to enhance the fish quality and textural properties of common carp fillets.

CZECH SUMMARY

Produkční účinnost technologicky upravených obilovin v chovu tržních kaprů

Jan Másílko

Kapr obecný (*Cyprinus carpio*, L.) je jednou z nejdůležitějších sladkovodních ryb chovaných na světě. Na našem území, resp. v České republice, má chov kapra dlouholetou tradici a nezaměnitelnou tvář v rybniční akvakultuře. Tato produkce je dosahována při použití převážně polo-intenzivního způsobu chovu, tzn. kombinací přirozené potravy a přikrmování doplňkovými krmivy, především obilovinami. A právě spotřeba krmiv, v našem případě obiloviny, tvoří jednu z nejvýznamnějších nákladových položek v chovu kaprů. Odhaduje se, že tyto náklady mohou být kolem 30–35 % z celkových nákladů. Cílem každého rybářského podniku je tyto náklady co nejvíce snížit a dosáhnout výrazného ekonomického efektu.

Jednou z možností jak snížit tyto náklady je zvýšení produkční účinnosti obilovin jejich vhodnou technologickou úpravou, která není ekonomicky náročná a pro rybníkářskou praxi lehce dostupná popřípadě nenáročná na technologii a obsluhu. Tyto technologické úpravy obilovin se mohou projevit příznivě v ekonomice chovu tím, že se zvýší nutriční hodnota, přijatelnost a zejména stravitelnost těchto upravených krmiv, a tím dojde i k vyššímu přírůstku ryb. Díky lepší stravitelnosti a lepšímu využití technologicky upravených obilovin kaprem může dojít i ke snížení zátěže okolního prostředí rybničních vod o nestravitelné a nevstřebatelné živiny (metabolity), především celkový fosfor (TP).

Cílem první studie bylo vyvinout růstový model pro růst kaprů v polo-intenzivním chovu během vegetační sezóny a zjistit, který z těchto modelů bude nejvhodnější. Pro přikrmování kaprů byly požity technologicky upravené obiloviny (a to mačkané) a neupravené obiloviny. Pro hodnocení jsme vyvinuli 5 lineárních modelů. První model s označením M1 je lineární smíšený model s náhodným absolutním členem. Druhým modelem s označením M2 je lineární smíšený model s náhodným lineárním členem. Model M3 je lineární smíšený model, který má náhodné oba členy, jak absolutní, tak lineární. Model 4 je definován jako model M3 spolu s mocninnou funkcí rozptylu z odhadových dat, která měla za úkol vysvětlit heteroskedasticitu. M5 je modelován jako model M4 spolu s mocinnou funkcí rozptylu, která byla modelována zvlášť pro každé krmivo. Z těchto pěti modelů byl vyhodnocen jako nejlepší model s označením M5. Součástí této studie bylo určit produkční účinnost mechanicky upravených obilovin (mačkání). Z dosažených výsledků je zřejmé, že kapři přikrmovaní mačkanými obilovinami vykázali lepší růst a nižší konverzi krmiva (FCR) a dále nižší variabilitu v tržní hmotnosti kaprů.

Studie 2 porovnává produkční účinnost mechanicky upraveného triticale (mačkání a šrotování) a neupraveného triticale (celé zrno) v chovu tržních kaprů. Z produkčních ukazatelů byly vyhodnocovány zejména konverze krmiva, Fultonův kondiční ukazatel, obsah tuku a výtěžnost filet. Dle dosažených výsledků lze říci, že tržní kapr je schopen lépe využít mechanicky upravené obiloviny, a to díky vyššímu přírůstku a nižší konverzi krmiva, což může vést ke snížení krmných nákladů v chovu tržních kaprů o 10 až 14 %. Podle dosažených výsledků může být konstatováno, že mačkání či šrotování triticale nemá výrazný vliv na Fultonův kondiční ukazatel či výtěžnost filet v porovnání s kapry, jenž byli přikrmování neupraveným triticale, a to za shodných provozních podmínek rybničního managementu.

Třetí studie popisuje možné dopady technologicky upravených obilovin (šrotování, mačkání, hygienizace) na životní prostředí v rybniční akvakultuře. Dle dosažených výsledků může být konstatováno, že díky technologickým úpravám obilovin (především hygienizací), dochází ke snížení znečištění rybníků o nestravitelné a nevyužitelné živiny, především celkový fosfor (TP), a to díky žádoucí konverzi živin do biomasy přírůstku ryb, a tím k jejich odčerpání. Dle dosažených výsledků lze očekávat přímou úsporu TP, který vstupuje do povodí, a tím i dalšímu snížení vstupů TP do recipientů povrchových vod. Úpravy obilovin, mohou být důležité pro udržitelné rybniční hospodaření zaměřené především na zlepšení bilance fosforu v rybničních soustavách.

V současné době se zvyšující se úrovní životního stylu jsou kladeny i vyšší nároky na kvalitu rybího masa. A právě i u spotřebitelů se zvyšuje poptávka po kvalitní surovině. Senzorické vlastnosti, resp. texturní vlastnosti (zejména tuhost, soudržnost, pružnost a žvýkatelnost), kapřích filet mohou být ukazatelem pro kvalitu rybích produktů, resp. filet. Výše uvedené texturní vlastnosti byly zjišťovány u kaprů z extenzivního a polo-intenzivního chovu. Dle dosažených výsledků (Studie 4) je zřejmé, že texturní vlastnosti, zejména tuhost masa, závisí na způsobu chovu tržních kaprů, dále pak na strategii přikrmování, rybničním managementu a obsahu tuku v rybím mase. Neboť kapři z polo-intezivního chovu se vyznačovali statisticky ($P < 0,05$) vyšším obsahem tuku, a naopak statisticky ($P < 0,05$) křehčí strukturou svaloviny.

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