DIFFERENCES IN SENSORY CHARACTERISTICS, CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF FARMED AND WILD-CAUGHT TILAPIA AND THEIR EFFECT ON SHELF LIFE

Jimmy Byaruhanga
Ministry of Agriculture, Animal Industry and Fisheries, Entebbe, Uganda
byaruhangajimmy18@gmail.com
jimmy@unuftp.onmicrosoft.com

Supervisors:
Hildur Inga Sveinsdóttir
hilduringa@matis.is

Aðalheiður Ólafsdóttir
adalheiduro@matis.is

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ABSTRACT

Nile tilapia (*Oreochromis niloticus*) is an economically important freshwater fish species in Uganda. The intensive farming of Nile tilapia and the decline in wild-caught tilapia have made farmed tilapia more available to consumers and mainstream seafood markets. This study aimed to evaluate the sensory characteristics, shelf life, and chemical composition of farmed tilapia compared with wild-caught tilapia, and to assess whether existing Quality Index Method (QIM) schemes available in the literature for tilapia, developed primarily for wild-caught fish, can also be applied to farmed tilapia. There was a significant difference (P=0.01) in fat content, with 2.36±0.44 g/100 g of muscle for farmed tilapia and 1.14±0.42 g/100 g of muscle for wild caught tilapia. The difference in water content was significant between farmed and wild-caught tilapia ($p<0.05$). The water content of farmed tilapia was 77.65±0.43%, and that of wild-caught tilapia was 79.47 ± 1.02 %. Higher Quality Index (QI) scores were recorded for wild-caught tilapia than for farmed tilapia throughout the storage period. A high correlation of R^2 =0.829 between QI and storage time for wild and R^2 =0.726 for farmed was recorded. On GDA, positive odour and flavour attributes were higher in farmed than in wild-caught fish. Negative odour and flavour attributes were more prominent in wild-caught than in farmed tilapia. The QI scores increased differently with storage time but showed a linear relationship in both groups. This indicates that the revised QIM scheme is applicable to both farmed and wild-caught tilapia.

KEY WORDS: Tilapia, sensory evaluation, physical properties, chemical composition, Uganda.

CONTENTS

1 INTRODUCTION 1

1.1 Research objectives 2

2 LITERATURE REVIEW 3

2.1 Description of Nile Tilapia (*Oreochromis niloticus*) 3

2.2 Quality changes in fish and fishery products 3

2.2.1 Microbial changes 3

2.2.2 Biochemical changes 4

2.2.3 Sensory changes 5

2.3 Shelf life of fresh fish 5

2.4 Methods for evaluation of fish freshness and quality 6

2.4.1 Sensory evaluation 6

3 METHODOLOGY AND MATERIALS 7

3.1 Raw materials 7

3.2 Experimental design 7

3. 2 Composition 8

3.3 Colour 8

3.3 pH determination 8

3.4 Sensory evaluation 8

3.4.1 QIM scheme 9

3.4.2. Sensory evaluation of cooked tilapia with GDA 10

3.5 Data analysis 11

4 RESULTS AND DISCUSSIONS 12

4.1 Composition 12

4.2 Colour measurement. 12

4.3 pH measurement. 13

4.4 Fatty acid composition. 13

4.5 Sensory evaluation. 14

4.5.1 QIM scheme. 14

4.5.2 GDA results 22

4.5.3 Correlation between QIM and GDA results. 25

5 CONCLUSION AND RECOMMENDATIONS 26

ACKNOWLEDGEMENTS 28

REFERENCES 29

APPENDIX 32

LIST OF FIGURES

Figure 1. Growth of farmed tilapia compared with wild caught tilapia………………………..2
Figure 2. Nile tilapia (Orechro-mis niloticus) (FishBase 2007)………………………………3
Figure 3. Experimental design of the study.. 7
Figure 4. CEILAB colour chart (left) and schematic representation of the locations where colour measurements were performed (right). 8
Figure 5. Evaluation of panellist performance using a revised QIM Scheme (Rodriques 2020) for the evaluation of freshness of whole and gutted farmed or wild caught tilapia. 14
Figure 6. Change in the average skin brightness score with increasing storage time. 15
Figure 7. Changes in average score of the abdominal colour with increasing storage time. ... 15
Figure 8. Changes in the average texture score with increased storage time. 16
Figure 9. Change in average score of the colour of the cornea with increase in storage time. 16
Figure 10. Changes in average score of the colour of the pupil with increased storage time. . 17
Figure 11. Average score of eye shape changed with increased storage time. 17
Figure 12. Average score of gill colour as a function of storage time. 18
Figure 13. Average mucus score changes with increased storage time. 18
Figure 14. Changes in the average score of gill odour with increased storage time. 19
Figure 15. Average score of internal abdominal walls with increase in storage time. 19
Figure 16. Average score for blood colour changes with increased storage time. 20
Figure 17. Graph of the linear relationship between the quality indices of farmed and wild-caught tilapia and storage time. 21
Figure 18. Changes in musty and earthy odours on days 11, 16, and 17. 23
Figure 19. Changes in potato and milk odours on days 11, 16, and 17. 23
Figure 20. Changes in sour and TMA odour for days 11, 16, and 17. 23
Figure 21. Changes in spoilage odour on days 11, 16, and 17. 24
Figure 22. Changes in charr and earthy flavours on days 11, 16, and 17. 24
Figure 23. Changes in sweet and musty flavours on days 11, 16, and 17. 24
Figure 24. Changes in metallic and sour flavours on days 11, 16, and 17. 25
Figure 25. Changes in bitter and TMA flavour for days 11, 16, and 17. 25
Figure 26. Changes in spoilage flavour on days 11, 16, and 17. 25
Figure 27. How QI scores changed with increasing storage time without results of "blood in abdomen" attribute for farmed and wild caught tilapia. 43
Figure 28. How combined QI scores changed with increasing storage time without results of "blood in abdomen" attribute. 43

LIST OF TABLES

Table 1. Factors affecting fish spoilage in ice …………………………………………...…5
Table 2. Quality index scheme for tilapia. 10
Table 3. GDA table of attributes used in the study. 11
Table 4. Results of composition of farmed and wild-caught tilapia. 12
Table 5. Results of colour measurements for wild-caught and farmed tilapia.......................... 13
Table 6. pH measurements for farmed and wild-caught tilapia. 13
Table 7. Summary of fatty acid compositions of farmed and wild-caught tilapia. 13
Table 8. QIM evaluation with SD for farmed and wild-caught fish showing changes over increased storage time. 21
Table 9. GDA evaluation of farmed and wild caught tilapia on days 11, 16, and 17. 22
Table 10. Final QIM scheme for tilapia with revised quality attributes 41
Table 11. Detailed fatty acid composition analysis for farmed and wild caught tilapia. 42

1 INTRODUCTION

World fish production has increased dramatically over the past 60 years, reaching approximately 179 million tons in 2018, valued at $401 billion (FAO, 2020). Aquaculture production accounted for 46% of total production and 62% of the total sale value. Aquaculture is one of the fastest-growing food-producing sectors globally, with development, expansion, and intensification occurring in practically every region (Subasinghe et al., 2009). The increase in global per capita fish consumption from 9.0 kg in 1961 to 20.5 kg in 2018 (FAO, 2020) indicates an improved preference and increased demand for fish as a source of high-quality nutrients. Moreover, declining fish stocks and plateauing production from capture fisheries, with most fishing areas currently at maximum potential, are indicators that capture fisheries alone cannot meet the growing human demand for fish. Thus, aquaculture is expected to bridge the supply demand gap (Subasinghe et al., 2009). In Uganda, fish accounts for more than 43% of the protein consumed, with an annual per capita consumption of 12.5 kg in 2013, higher than the African average of 10.1 kg at that time (Adeleke et al., 2021). With a population estimate of 44.3 million people and a projected population of 74.5 million by 2040 (UNDESA, 2019), Uganda currently requires at least 908,200 tons of fish per year for the local market and will require at least 1,527,300 tons by 2040 if Ugandans are to consume fish at the global average per capita fish consumption level of 20.5 kg (FAO, 2020). To satisfy both local and international markets, Uganda will need to invest more and expand its aquaculture industry to produce high-quality fish products.

The intensive farming of tilapia, in particular, *Oreochromis niloticus*, is rapidly growing globally, making it the second most widely farmed fish in the world and the most farmed fish in Uganda. Tilapia is an important fish species for aquaculture in different regions of the world. They are characterised by fast growth, adaptability to a wide range of environmental variables, disease resistance, and high flesh quality. They can reproduce under varying culture conditions and readily convert food low in plant protein to high-quality flesh, making them one of the most profitable species in aquaculture (El-Sayed, 2006). The global tilapia market is growing at a rate of 10-12% per year, more commonly in fresh form (FAO, 2020). Tilapia have grown in importance from being a low-cost, high-protein food fish employed by governments and development agencies to feed the poor in rural areas to a highly domesticated livestock with annual sales amounting to over $2billion globally according to the FAO 2020.

According to FAO statistics, farmed tilapia production in Uganda grew rapidly from 600 t (tonnes) in 2000 to approximately 50,000 t in the early 2010 to 80,000 t in 2020 (Figure 1). The production in 2000 was composed of 400 tonnes of Nile tilapia (*Oreochromis niloticus*) and 200 tonnes of redbelly tilapia (Tilapia zillii), whereas from the early 2010s to 2020, the production was solely Nile tilapia. The share of farmed tilapia in total tilapia production (farmed and wild) increased from less than 1 percent in 2000 to nearly 50 percent in the early 2010s. This resulted in the rapid growth of farmed tilapia production as well as a decline in wild-caught tilapia production, estimated at nearly 100,000 t in the early 2000s to approximately 50,000 t in the early 2010s.

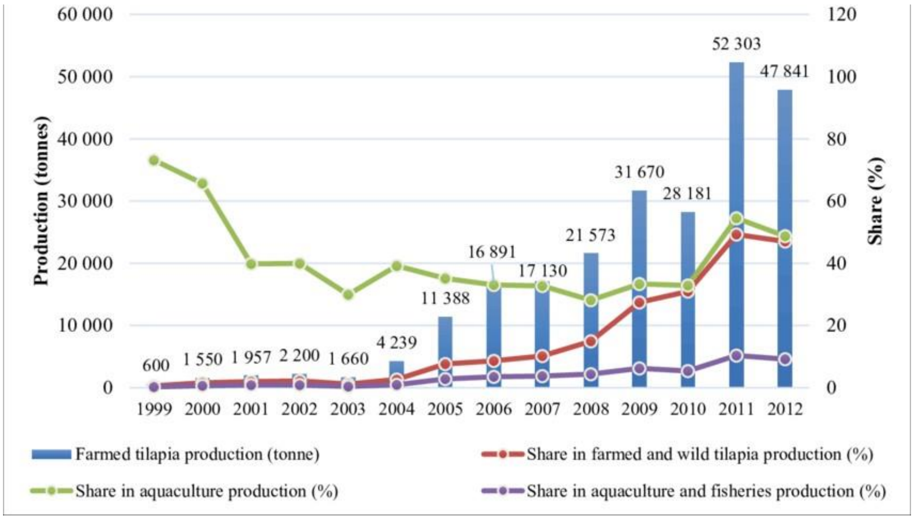

Figure 1. Growth of farmed tilapia compared with wild caught tilapia.

Nile tilapia was introduced in Uganda in the 1940s by colonial masters and cultured at the subsistence level to meet local protein needs, ensure food security, and fight malnutrition-related diseases (MAAIF, 2012). However, as production and handling techniques have improved, tilapia has moved into mainstream fish markets both locally and regionally, and there is a growing demand for Uganda tilapia in international markets (UFPEA 2021). The increase in aquaculture production has made tilapia more available and affordable to consumers, making it the most popular fish species in Ugandan fish markets.

The majority of Ugandan tilapia consumers prefer whole, fresh fish over processed fish (Feidi, 2004). Farmed and wild-caught tilapia are marketed together in retail markets. There is a common perception among consumers regarding the quality of farmed tilapia. Many consumers believe that farmed fish, including tilapia, are inferior in quality to wild-caught fish and claim that fish feeds contain dead animals, animal waste (feathers, guts, blood, etc.), and hormones (Feidi, 2004). However, there is no solid evidence to support these claims. The lack of a national residue monitoring plan, absence of fish handling infrastructure and facilities in some fish farms, failure to adhere to standards that promote good handling and hygiene, problems associated with water quality and algal blooms, misuse of veterinary drugs, use of antimicrobials, contaminated feed, pesticide residue in water, and limited information on quality changes in farmed tilapia may be the reason behind this speculation (MAAIF, 2019).

Therefore, extending the shelf life and maintaining the freshness and quality of fresh tilapia are key to its profitability. Understanding the sensory attributes and chemical composition of tilapia from both capture and wild sources and their effect on shelf life is important to achieve this goal. This project aimed to determine whether the two spoil at different rates and, if so, hypothesise about what may be the cause. Furthermore, the applicability of a previously developed Quality Index Method (QIM) scale available in the literature on wild and farmed tilapia from Uganda was evaluated to provide additional tools to the community.

1.1 Research objectives

The primary objective of this study was to determine the sensory characteristics and chemical composition of farmed tilapia compared to captured tilapia stored in ice and their effect on the shelf life of whole, gutted fish. Furthermore, we determined whether the Quality Index Method (QIM) schemes available in the literature for tilapia, specifically capture, are also applicable to farmed fish and whether modifications need to be made to the scale to improve its function.

2 LITERATURE REVIEW

2.1 Description of Nile Tilapia (*Oreochromis niloticus*)

Nile tilapia (Oreochromis niloticus) is an important fish species in the ecology of tropical and subtropical regions. It is the most popular species of bony fish in Africa (Offem et al., 2007). Nile tilapia is a native African freshwater fish species that inhabits shallow streams, ponds, rivers, and lakes (Diallo, 2020). They belong to the family Cichlidae. Tilapia have laterally compressed, deep bodies and are greyish or blackish in colour. Similar to other cichlids, their lower pharyngeal bones are fused into a single tooth-bearing structure. A complex set of muscles allows the upper and lower pharyngeal bones to be used as a second set of jaws for processing food, allowing a division of labour between the true jaws (mandibles) and pharyngeal jaws. This suggests that they are efficient feeders capable of capturing and processing a wide variety of food items. Their mouths are protrusible and are usually bordered by wide and swollen lips. The jaws have conical teeth. They have a long dorsal fin and a lateral line that often breaks towards the end of the dorsal fin and starts again two or three rows of scales below. Nile tilapia reproduce through mass spawning of a brood within a nest made by males. In such an arrangement, territoriality and sexual competition among males lead to large variations in the reproductive success of individuals in a group. Nile tilapia is a mouth-brooding species, which means they carry fertilised eggs and young fish in their mouths for several days after the yolk is absorbed. Nile tilapia can reach up to 60 cm in length, exceed 5 kg, and have a life span of up to 10 years. Male tilapia generally reach a larger length and size and grow faster than females (Nico et al., 2019). Nile tilapia can be found in most types of freshwater habitats, such as rivers, streams, canals, lakes, and ponds. It also occurs in brackish water but cannot survive long-term in full salt water (Froese *et al*., 2015).

Figure 2. Nile tilapia (O*rechromis niloticus*) (FishBase 2007**).**

2.2 Quality changes in fish and fishery products

Fish spoilage is any change that renders the product unfit for human consumption. Ideally, fish and seafood product spoilage is a consequence of various microbial, biochemical, and chemical breakdown processes (Huis Veld, 1996). The degree of processing and preservation, together with the storage temperature, determines whether fish undergo microbial or biochemical spoilage or a combination of both. The initial quality loss is mainly due to postmortem autolytic activity and chemical degradation processes such as lipid oxidation (Sivertsvik et al., 2002).

2.2.1 Microbial changes

Bacterial changes are considered the most important cause of fish spoilage (Gram and Dalgaard, 2002). This is because spoilage is often a result of off-odours and off-flavours caused by bacterial metabolism (Gram *et al.,* 1990). The growth of a specific microorganism during storage depends on several factors, the most important being the initial microbial loading at the start of storage, the physicochemical properties of food, the processing method used in the production of the food, and the external environment of the food, such as the surrounding gas composition and storage temperature (Kilcast and Subramaniam, 2000).

Several authors have reported that microorganisms associated with most fish and fishery products reflect the microbial population in their environment (Adams and Moss, 2008; Gram and Huss, 1996). However, the total number of organisms varies significantly depending on various factors. The wide range of environmental habitats and variety of processing and handling practices are factors that determine the initial contamination of fish and fish products (Gram *et al*., 1996). The part of microflora which will ultimately grow on fish products will be determined by intrinsic factors which greatly influence fish microbiology and spoilage, mainly the pH in the flesh (Huss *et al*., 1997).

Freshly caught fish are sterile. This is because the immune system of the fish prevents bacteria from growing in the flesh. When fish die, their immune system collapses, allowing bacteria to proliferate freely (Huss, 1988). The flesh becomes rapidly contaminated by surface and intestinal bacteria from equipment, machinery, and humans during handling and processing. This is the case with gutted tilapia, where most of the microbial contamination occurs during gutting and subsequent handling (Adams and Moss, 2008). Opening fish by gutting creates conditions for the invasion of bacteria and oxidation of lipids, as it increases the surface area to volume ratio of the product (Adams and Moss, 2008).

2.2.2 Biochemical changes

The biochemical composition of fish and their interrelationships with postmortem factors contribute significantly to the perishability of fish as a food commodity because they determine the initial contamination (Huss *et al.,* 1997). The physical, chemical, and bacteriological characteristics of fish tend to vary with species, feeding habits, season (Smith *et al*., 1980), spawning cycles, methods of catching, fishing ground (Whittle *et al.,* 1980), size, age environment, initial microbiological load, and possibly geographical location (Shewan, 1977). These factors are observed in wild environments, the sea, and inland waters. According to Huss (1995), farmed fish may show variations in chemical composition; in this case, most factors are controlled, and the chemical composition can be predicted. During the storage of fish on ice, several changes occur. These include changes in protein and lipid fractions, degradation of nucleotides with the subsequent formation of amines (volatile and biogenic), hypoxanthine, and the action of certain bacteria (Surti *et al*., 2001). As a result of these changes, deterioration in sensory quality, loss of nutritional value, and negative attributes of the physical properties of fish muscle have been reported (Olafsdottir *et al*., 1997).

The pH of the muscle of live fish is close to neutral (pH 7) (Huss 1995). During the later stages, pH is more or less constant or slightly increases due to the formation of basic compounds (Shewan, 1977, Huss, 1988). Although changes in pH are generally small, they are of great importance. The post-mortem pH is the most significant factor influencing the texture of the meat and the degree of gaping, for example, the rupture of connective tissue (Huss 1995). This is because even minor changes in pH drastically affect the properties of the connective tissue, and the net surface charge on the muscle proteins is reduced, causing them to partially denature and lose some of their water-holding capacity (Huss, 1995).

One of the most important chemical spoilage processes is the changes in the lipid fraction of fish. After death, the lipids in fish undergo two major changes: lipolysis and auto-oxidation (Hardy, 1980) which are important chemical spoilage processes in fish (Huss, 1994). Fish fats (lipids) contain a high proportion of polyunsaturated fatty acids that react with oxygen in the atmosphere. The end products are aldehydes and ketones, which lead to a strong rancid flavour normally associated with spoilt fatty fish (Huss, 1994). Fish stored on ice or at ambient temperatures does not seem to undergo lipid oxidation as a dominant spoilage process; however, in the later stages of spoilage of fattier species such as trout, sardine, herring, and mackerel, rancid flavours affect acceptability (Kolakoski, 2000).

2.2.3 Sensory changes

Seafood products are perishable, and their sensory characteristics depend on various factors, including handling, storage methods, and time. The sensory characteristics of different species vary (Martinsdottir *et al*., 2001). The first sensory changes in fish stored on ice are related to appearance, texture, flavour, and odour. Physical properties such as firmness and appearance are related to storage days because of cellular flaking of autolytic and microbial changes (Fletcher and Statham, 1988). Fish after harvest contain low levels of volatile compounds which contribute to freshness odour, while characteristic sour and rotten odours at the end of shelf life originate from short-chain fatty acids, alcohols, sulphur compounds, and amines generated by microbial activity (Olafsdottir *et al*., 1997). The quality changes in fish are also directly affected by the initial quality of the raw material (Olafsdottir *et al*., 1997). Generally, the spoilage of marine temperate water fish is characterised by the development of offensive, fishy, rotten, H_2S off-odours, and off-flavours. This is different from some tropical freshwater fish, in which sweet, fruity, sulphydryl related off-odours and off-flavours are more common (Gram and Huss, 1996).

2.3 Shelf life of fresh fish

The shelf life of fish is the time it is fit for human consumption or the period from when fish is caught until it is no longer fit for consumption (Huss, 1995). Spoilage due to microbial activity is the main limitation of the shelf life of fresh fish products. Another cause of spoilage may be rancidity, especially in fatty fish species. The flesh of newly caught fish is also free of bacteria. However, considerable amounts of bacteria may be present in the viscera, gills, and skin. When fish are stored whole in ice, the deterioration caused by bacteria is minimal during the first few days of storage. The flavour and odour compounds that characterise newly caught fish decrease and disappear in the first few days of storage in ice, and the fish flesh becomes almost flavourless and odourless (Table 1). The number of hydrogen sulphide bacteria increases rapidly in the flesh, using various compounds to grow, resulting in increasingly sulphur and nitrogenous volatiles with off-putting odours until most people evaluate the fish as unfit for consumption.

Under normal chilled storage, the shelf life of fish and fish products is limited by the growth and biochemical activities of aerobic specific spoilage organisms (SSO). However, enzymatic and microbiological activity is greatly influenced by temperature; therefore, the shelf life of fish and fish products is markedly extended by cooling.

Table 1. Factors affecting fish spoilage in ice (Huss, 1995).

Factors affecting spoilage rate	**Slower rate**	**Faster rate**
Shape	Flat fish	Round fish
Size	Large fish	Small fish
Fat content in the flesh	Lean species	Fatty species
Skin characteristics	Thick skin	Thin skin

2.4 Methods for evaluation of fish freshness and quality

Fish is a highly perishable product. With unstable supplies and the fact that fresh fish can be stored only for a short time, freshness is one of the most important aspects of fish and fish products. For all kinds of fish and fishery products freshness makes a major contribution to the quality of fish and fishery products (Olafsdóttir, 1997). From the moment the fish are caught, the deterioration process starts, and the quality of the fish for use as a food product is affected. There are different methods used to evaluate and analyse fish freshness, including sensory, microbial, physical, and chemical analyses.

2.4.1 Sensory evaluation

Assessment of whole fish freshness by Quality Index Method (QIM)

The Quality Index Method was first proposed in Australia (Bremner, 1985). It is based on well-defined sensory characteristics, and different scores are assigned to each attribute according to its importance. The schemes have descriptions of each sensory attribute, which are evaluated separately and given a score from 0 to 3. This method has an advantage over classification schemes because no unjustified emphasis is placed on a single attribute. The scores are added to give a quality index. The schemes are developed in such a way that a linear relationship exists between QIM-index points and storage time of fish in ice; therefore, shelf life can be predicted (Hyldig and Nielsen, 1998; Luten and Martinsdóttir, 1998). This possibility is very useful for the fish industry to determine the suitable processing method for raw materials and the duration of storage. QIM is based on well-defined characteristic changes in raw fish that occur in the outer appearance of eyes, skin, and gills, as well as odour and texture, and a score system from 0 to 3 demerit (index) points. The descriptions of each score for each parameter are listed in the QIM scheme table. The scores for all the characteristics are summarised to give an overall sensory score, the Quality Index. QIM is an objective method that is easy to work with compared to other sensory methods, as it includes instructions and easily understood illustrated material.

Assessment using QDA.

Quantitative Descriptive Analysis (QDA) is a method used mostly on cooked fish samples to determine the maximum storage time and provide a complete description of the sensory properties/characteristics of the sample/product (Sveinsdottir et al. 2003). It is based on the principles of the ability to detect and describe the quantitative and qualitative sensory properties/attributes by a trained panel under the guidance of the panel leader (Stone and Sidel 2004). The panellists should be able to detect and describe the intensity of the product attributes. The terminologies to be used to describe each characteristic are first agreed upon during an interactive session among panellists, together with the panel leader, who is not involved in the development of terminologies but guides the communication process. The panellists are then trained on the characteristics of the sample and the definitions which are developed. The panellists then participate in the evaluation of the sample, usually carried out in an independent booth to minimise distraction and interaction among panel members.

Generic Description Analysis (GDA) is based on the same principles as QDA, except that one does not need to include a complete description of the sensory properties/characteristics of the product which makes it more flexible than QDA.

3 METHODOLOGY AND MATERIALS

3.1 Raw materials

Thirty kilograms of fresh tilapia were purchased from Yalelo fish farm (farmed) in Buikwe district located in the eastern part of Uganda and from Kiyindi Landing site (wild caught) from Buikwe district. All fish samples were harvested on 22/02/2024, with wild fish samples caught the night before. All samples were iced after harvest. The samples from the Kasenyi Landing site were labelled A, and fish from the Yalelo cage fish farm were labelled B, where A represents wild-caught tilapia and B represents farmed tilapia. The fish were then transported to Fresh Perch (u) Limited, a fish processing establishment, where they were gutted, iced, and packed in thermally insulated expanded polystyrene (EPS) boxes. The samples left Entebbe International Airport by air on 23/02/2024, reached Keflavik Airport, Iceland on 28/02/2024, and arrived at Matis (Icelandic Food and Biotech R&D) on 29/02/2024.

After reaching Keflavik Airport, Iceland, the fish were cleared by the authorities in Iceland and transported to Matis, where the study was conducted. Upon arrival at Matis 6 days after harvest, the fish surface temperatures were 6.2°C in box A and 6.4°C in box B.

Ten fish from each group were separated from the rest, stored in separate boxes, and iced. These were used for sensory evaluation, where they were always picked for evaluation and returned. Four fish from each group were isolated from the rest and stored at a higher temperature (8°C) to accelerate spoilage and were used to train the sensory panellists. The remaining fish samples were used for GDA.

3.2 Experimental design

The experimental design of this study is illustrated in Figure 3.

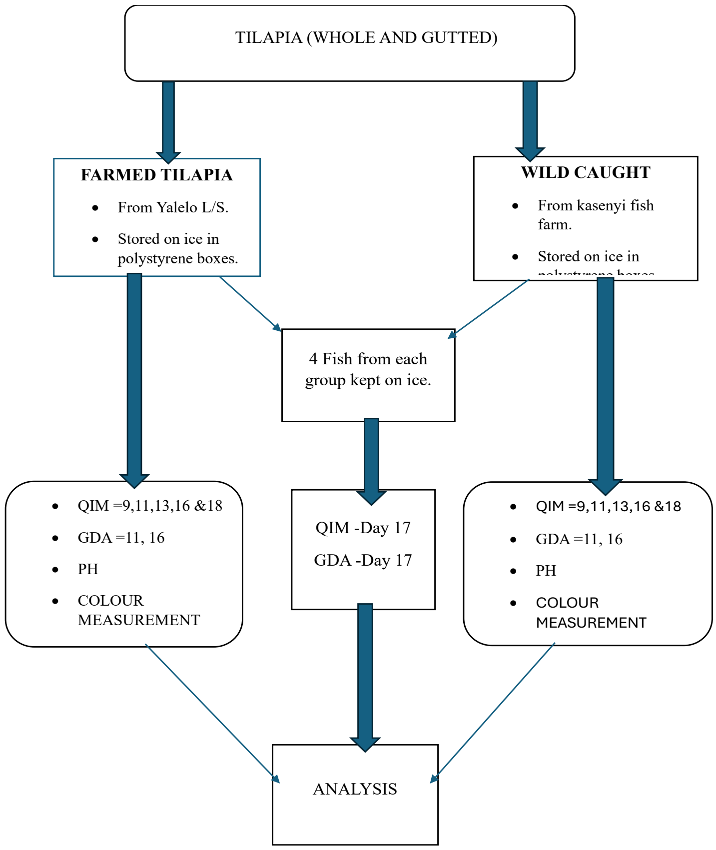

Figure 3. Experimental design of the study.

3. 2 Composition

The fat and moisture contents of tilapia muscle from the raw fish materials were determined according to the methods described by Smedes et al. (1999) and Feldsine et al. (2002). The fatty acid composition was determined following fatty acid methylation using gas chromatography (AOAC 996.06).

3.3 Colour

Colour measurements were taken from the surface of the fish muscle using a Konica Minolta CR-400 colorimeter. The changes or differences in the colour of the samples will be determined according to the CIELAB system (L*a*b* colour space). In this system, L* represents the colour lightness on a 0-100 scale from black to white; a* is the position between red (+) and green (+); and b* is the position between yellow (+) and blue (-). Three whole tilapia fish were collected from each group and filleted. Measurements were taken at three points on each fillet from each group (Figure 4).

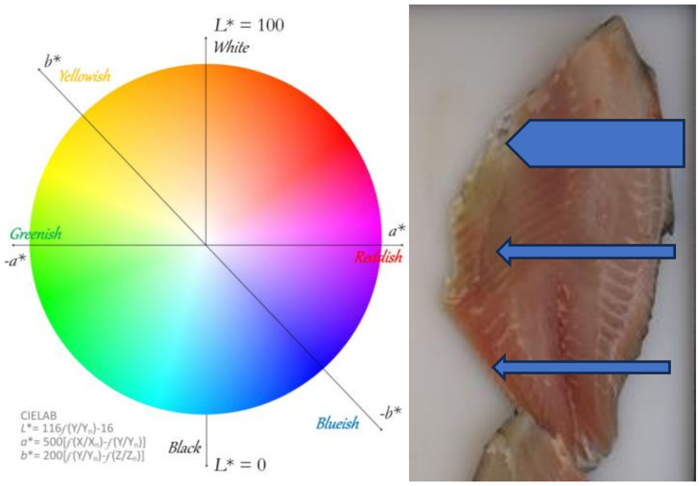

Figure 4. CEILAB colour chart (left) and schematic representation of the locations where colour measurements were performed (right).

3.3 pH determination

The pH was measured using a pH meter (Micro pH vision 6071).

3.4 Sensory evaluation

Eight to ten panellists, sensory panellists, and employees of Matis and two GRÓ FTP fellows participated in the sensory evaluation of raw tilapia (QIM), and 10 panellists for cooked (GDA) all Matis employees. Four fish from each group were stored at high temperatures prior to the main sampling to obtain fish that had started to spoil and could act as training fish for the sensory panellists to demonstrate the spoilage characteristics of tilapia. Wild and farmed tilapia were evaluated using the QIM scheme on days 9, 11, 13, 16, 17, and 18 of storage. In these samplings, the same fish were used repeatedly; therefore, some temperature abuse was inevitable during the evaluation. Further, QIM and GDA were used to evaluate the samples at the chosen sampling points. This provided the opportunity to ensure that any abnormalities or problems with the QIM scale would not go unnoticed, making its evaluation more effective. Therefore, providing an opportunity for improvements of the scale as needed to better accommodate the differences between these raw materials.

To determine the effects of temperature abuse caused by the repeated evaluation of the same fish throughout storage, a single evaluation on day 17 of storage was performed using both QIM and GDA on fish that had been kept at a stable low temperature of 0°C on ice.

The panellists participating in the sensory sessions were first trained on the use of both methods before proceeding to evaluate the fish. The panellists were familiar with and had experience using the QIM and GDA methods to evaluate other fish species, and some had encountered tilapia. The initial evaluation of whole tilapia by comparing the sensory attributes of fresh and old tilapia aimed to identify individual visible parameters that were noticeably different between the two sample groups.

3.4.1 QIM scheme

The sensory attributes of tilapia were evaluated using the Quality Index Method (QIM) developed by Rodrigues *et al.* (2015) which was improved during the initial evaluation in six different sessions. The sessions started 9 days after harvest or slaughter.

In the first evaluation session, on day nine, 10 fish from each group were evaluated. In the following session, the number was reduced to five fish from each group which were randomly selected from the previous 10 selected on the first day of sampling. All samples were randomly distributed on a table and assigned random codes. Additionally, four fish were kept on ice throughout the study, as previously stated.

During the evaluation sessions, the panellists were given extra sheets of paper to record any other observations that were not included in the QIM scheme which could be used as an attribute of spoilage of tilapia with storage time. The samples were evaluated using the QIM scale presented in Table 2.

Table 1. Quality index scheme for tilapia.

Quality parameter		Description	Points
Overall appearance	Skin brightness	Iridescent/bright	0
		Less bright	1
		Dull	2
	Colour of abdomen	White, pink, no yellow colour	0
		Slightly yellowish	1
		Yellowish	2
	Texture	In Rigor	0
		Finger mark disappears rapidly	1
		Finger leaves mark over 3 seconds	2
Eyes:	Colour of cornea	Transparent, clear	0
		Slightly cloudy	1
		Cloudy, opaque	2
	Colour of pupil	Bright black	0
		Slightly grey and dull	1
		Dull grey	2
	Form	Convex	0
		Flat	1
		Concave	2
Gills:	Colour/ appearance	Bright red to violet	0
		Less-bright red/ red brown	1
		Discoloured/ brown	2
	Mucus	Transparent, not sticky	0
		Slightly milky, and sticky	1
		Brown, clotted	2
	Odour	Fresh, seaweed	0
		Slightly metallic	1
		Rancid	2
Abdomen:	Internal abdominal wall	Bright silver colour with black dots	0
		Less bright with black spots	1
		Dull, yellowish, with black dots	2
	colour of blood	Bright red or not present	0
		Dark red	1
		Brown	2
Quality Index (0 - 22)			

3.4.2. Sensory evaluation of cooked tilapia with GDA

The sensory attributes used during the evaluation of the cooked samples are listed in Table 3. Four fish from each group were filleted and deskinned. The deskinned fillets were cut into portions, 5-6 cm long and approximately 2-3 cm wide. The portions were placed in aluminium boxes coded randomly with three-digit numbers and cooked in a pre-heated electric oven (Convotherm, Eglfing, Germany) with circulating air and steam at 95-100°C for 5 minutes. Each panellist evaluated duplicates of samples (four samples in total) in a random order in one session per sampling day.

Eleven panellists, all employees of Matis, familiar with the QDA method, and some experienced in the sensory evaluation of tilapia, were trained during one session to evaluate cooked tilapia using the QDA method. The panel observed differences in the odour and flavour of the tilapia. A list of sensory attributes to describe samples was made under the guidance of the panel leader, and the panel was trained to describe the intensity of each attribute for a given sample using an unstructured scale (from 0 to 100), as indicated in Table 3. The table was extracted from Cyprian et al. (2008). All sample observations were conducted according to international standards (ISO, 1988). The panel evaluated the cooked samples, coded with three-digit numbers without information about the storage time, using a list developed during training. Each sample was randomly evaluated in duplicate. A computerised system (FIZZ, Version 2.0, 1994–2000, Biosystémes) was used for data recording and further processing.

Table 2. GDA table of attributes used in the study.

sensory attribute	short name	definition
ODOUR		
musty	O -musty	musty, mouldy
earthy	O -earthy	fresh earth
boiled potatoes	O -potatoes	whole freshly boiled potatoes
warm milk	O -milk	warm, sweet milk
spoilage sour	O -sour	spoilage sour
TMA	O -TMA	TMA, dried fish, amine
spoilage odour	O -spoilage	overall spoilage odour
FLAVOUR		
arctic charr	F -charr	fresh arctic charr flavour
earthy	F -earthy	fresh earth
sweet	F -sweet	characteristic sweet flavour of fresh fish
metallic	F -metallic	characteristic metallic flavour of fresh fish
musty	F -musty	musty, mouldy
spoilage sour	F -sour	spoilage sour
bitter	F -bitter	bitter, spoilage characteristic
TMA	F -TMA	TMA, dried fish, amine
spoilage flavour	F -spoilage	overall spoilage flavour

3.5 Data analysis

The mean values of QI, GDA, and sensory attribute scores were plotted separately against time using Microsoft Excel (2023). Panellists' performance was assessed using a panel check program (Version 1.3.2, Norway) on GDA data for each sampling day, and panellists who did not use the scale correctly and were unable to differentiate between samples were omitted. Analysis of variance (ANOVA) was performed on the results using the statistical program NCSS 2000 (NCSS, Utah, USA). The program (ANOVA) calculates multiple comparisons using Duncan's test to determine whether the sample groups are different. The significance level was set at $P<0.05$.

4 RESULTS AND DISCUSSIONS

4.1 Composition

Table 4 shows the composition of both farmed and wild-caught tilapia. The water content was 77.65±0.43 for farmed tilapia and 79.47±1.02 for wild-caught tilapia. Wild-caught tilapia had a higher water content than farmed tilapia. The difference in water content between farmed and wild-caught tilapia was significant (P-value =0.01 [P < 0.05]). The percentage of water/moisture content was within the acceptable range of 60%-80% (Tsegay et al. 2016). The results from both groups were lower than those reported by Alemu et al. (2013), which were 80.6% and 79.6% for male and female tilapia, respectively. However, the results of the present study were higher than those reported by Desta et al. (2019), which were 73.62±3.02 and 66.77±4.71 for pond tilapia and Lake Hawassa, respectively.

Similarly, farmed tilapia had a higher fat content than wild-caught tilapia. The fat content of farmed tilapia was 2.36±0.44, whereas that of wild-caught tilapia was 1.14 ± 0.42. There was a significant difference between the fat contents of both groups (P-value = 0.00018). Desta et al., 2019, reported similar results on fat content. They reported that the fat content of tilapia from ponds was 2.39±0.34 which is similar to what was obtained in the present study. However, his findings were different for tilapia in Lake Hawassa which was 3.98±0.55 higher than what was found in the current study. The results from the study, however, were within the limits/range for fish and fishery products, 0.5 to 8.5% (USDA, 2010).

Table 3. Results of composition of farmed and wild-caught tilapia.

Composition (%)	**Farmed**	**Wild**
Water content	77.65±0.43	79.47±1.02
Fat content	2.36±0.44	1.14±0.42

4.2 Colour measurement.

Colour is one of the most important parameters used to evaluate the quality of fish and fishery products (Ocano-Higuera et al., 2009). It also determines and influences the acceptability of the product by consumers. Haard (1992) reported that the initial colour of fishery products changed during storage in ice, affecting the quality of the product. The results of the colour measurements of farmed and wild-caught tilapia are shown in Table 5. The L * values for both farmed and wild tilapia were almost the same. No significant difference was observed between the L* values of farmed and wild tilapia. However, the a* value for wild-caught tilapia was slightly higher than that of farmed tilapia, with values of-2.68 for farmed tilapia and -3.61 for wild-caught tilapia. In addition, there was a significant difference in the a* values between the groups ($p<0.05$). The results indicated that fillets from farmed tilapia were redder than those from wild-caught tilapia. The b* values of farmed and wild-caught tilapia were 4.99 and 3.03, respectively, during the storage period. The b* values for farmed tilapia were generally higher, with significant differences between the two groups. This indicates that farmed tilapia were more yellowish than wild-caught tilapia.

Table 4. Results of colour measurements for wild-caught and farmed tilapia.

Group	L*	a*	b*
Farmed	48.6±2.6	-3.61 ± 1.75	4.99± 2.60
Wild	48.6± 2.0	-2.68 ± 1.45	3.03± 1.65

4.3 pH measurement.

The determination of pH is one of the most frequently used physical quality control methods for fish, seafood, and fish products, which is affected by changes in lipid hydrolysis, microorganisms, or enzymes (Varlik et al. 2000). In general, the pH of fish after capture is close to 7.0, but this value decreases rapidly immediately after death, as glycogen is converted to lactic acid and fish undergo rigor mortis. Most fish species reach postmortem pH values of 6.0–6.8 (Khalafalla et al., 2015). This measurement is important for determining the freshness and quality of fish products.

The pH values for wild tilapia were slightly higher than those for farmed tilapia, with values of 6.72 for wild-caught tilapia and 6.42 for farmed tilapia (Table 6). However, there was no significant difference in pH values between the two groups. Similar values were reported by Jimenez-Ruiz et al. (2023) and Montoya-Camacho et al. (2014), who obtained pH values of 6.48 and 6.77, respectively, for tilapia muscle stored under ice. The slight differences in the pH values of farmed and wild-caught tilapia may be related to diet, muscle type, season of the year, activity level, and stress during capture and post-harvest handling (Khalafalla et al., 2015).

Table 5. pH measurements for farmed and wild-caught tilapia.

Group	pH
Farmed	6.42 ±0.13
Wild	6.72 ±0.14

4.4 Fatty acid composition.

A total of 28 fatty acids were identified in both wild and farmed tilapia samples. Table 7 presents a summary, with Table 12 in the Appendix containing the complete list. Wild-caught tilapia had a slightly higher number of saturated fatty acids (SAF) than farmed tilapia. Palmitic acid (C16:0) was the most abundant SAF in both tilapia groups. Monounsaturated fatty acids (MUFA) were higher in farmed tilapia than in wild-caught tilapia. There was a significant difference in the MUFA levels between the two groups. The most common and abundant MUFA was oleic acid (C18:1n9). Wild-caught tilapia had the highest polyunsaturated fatty acid content compared to farmed tilapia. Wild-caught tilapia had a higher content of Omega 3 than farmed tilapia, with a significant difference. This difference could be related to the difference in lipid content and the ratio of triglycerides to phospholipids in the muscle.

Table 6. Summary of fatty acid compositions of farmed and wild-caught tilapia.

Fatty acids	Wild	Farmed
SFA	42.97±0.68	40.53±1.0
MUFA	20.97±3.75	35.13±2.62
PUFA	35.75±6.46	25.94±2.67
OMEGA 3	22.96±5.23	5.93±0.46
OMEGA 6	7.48±1.45	17.49±1.68

4.5 Sensory evaluation.

4.5.1 QIM scheme.

To effectively evaluate the effectiveness of the QIM scale, the performance of the panellists and how different attributes of the scale changed over time were analysed.

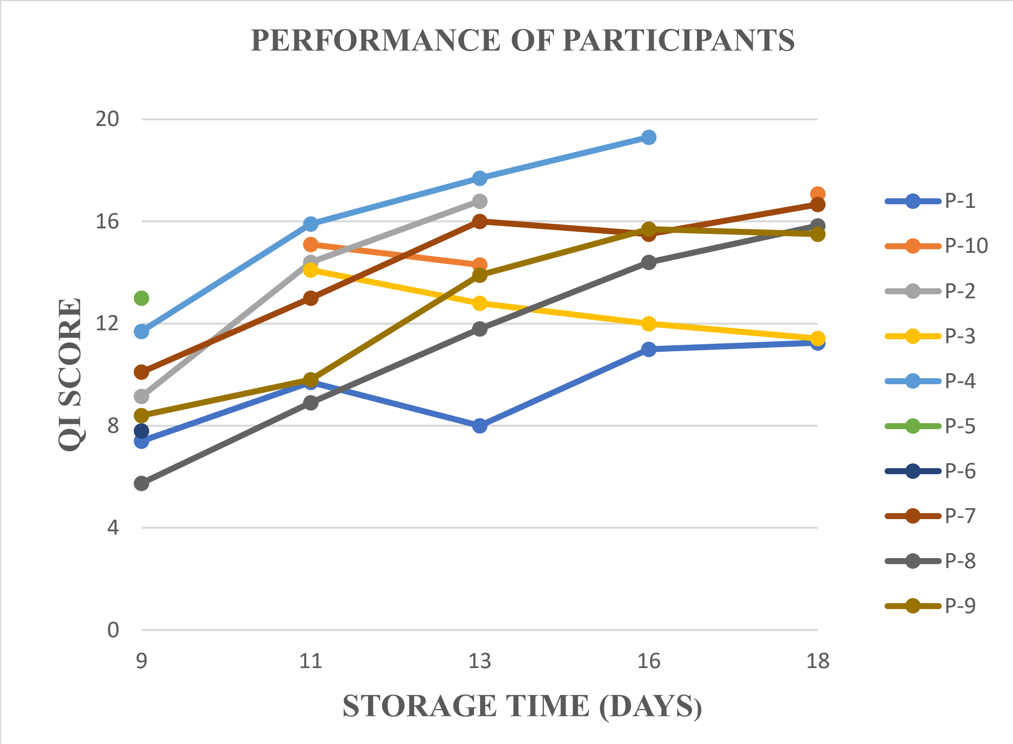

Figure 5. Evaluation of panellist performance using a revised QIM Scheme (Rodriques 2020) for the evaluation of freshness of whole and gutted farmed or wild caught tilapia.

The figure above represents the performance of the panellists based on the average QI for samples on day 9,11,13,16 and 18 of storage. Ten panellists evaluated the samples. The results showed that tilapia received increasing QI scores with storage time by most of the panellists. Unlike other panellists, panellists p-3 and p-10 had their scores reduced with storage time. P-10 recorded a high score on day 11, which was reduced on day 13. P-3 recorded high scores on day 11, which subsequently decreased on day 13, 16 and reached the lowest score on day 18. According to Martinsdóttir (1998), the QIM scheme is developed in such a way that a linear correlation is achieved between QIM-index points and storage time of fish on ice and that is how it is designed. Therefore, individual panellists providing results contrary to a majority panel, were using the scale in a wrong way, or had other factors influencing their decisions, as such data from panellists P-3 and P-10 was excluded from the QIM analysis.

Individual QIM scheme attributes

Eleven relevant attributes comprising four parameters were defined by assessors to describe the sensory changes of whole and gutted tilapia during storage. Three descriptors per attribute were used to evaluate quality variations. A quality index ranging from 0, indicating maximum freshness, to 22, with 18 as the point of rejection. Each attribute was assessed, and a graph was drawn to show how each attribute changed with storage time (Figure 6).

Figure 6 shows a graph of the average score against the storage time for skin brightness. The average scores of wild tilapia increased linearly from 0.7 on day 9 to 1.6 on day 18. The average scores for farmed tilapia increased linearly from day 9 at 0.5 to day 13 at 0.8, followed by a stepped increase between days 13 and 16 up to 1.4, and then a slight decrease to 1.0. These figures were reported by Vazquez et al. (2020).

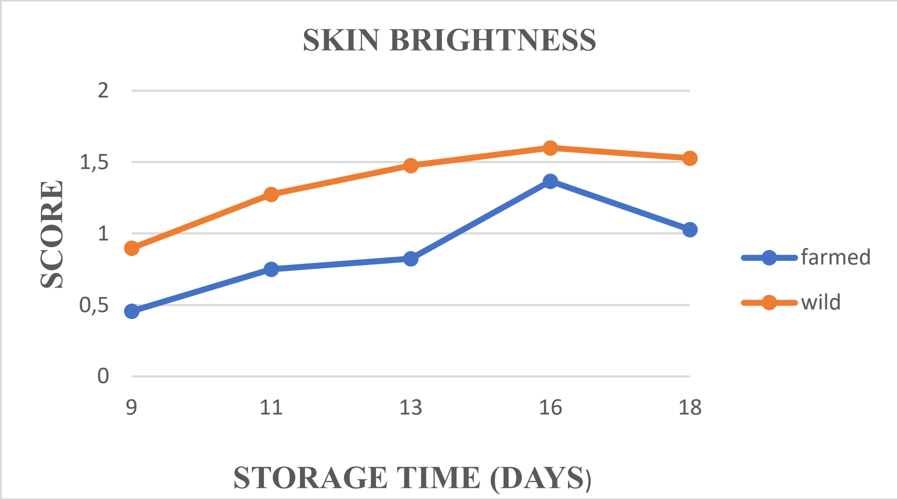

Figure 6. Change in the average skin brightness score with increasing storage time.

As storage time increased, tilapia developed a dull colour, indicating reduced freshness, with iridescence or brightness used to describe freshness (Figure 7).

Figure 7 shows a graph of the average score against the storage time for the colour of the abdomen. As storage time increased, the score also increased for both groups, with wild-caught tilapia receiving higher scores than farmed tilapia. As storage time increases, tilapia develops a yellowish colour on the abdomen which indicates a reduction in freshness. Whitish or pinkish colours indicate freshness.

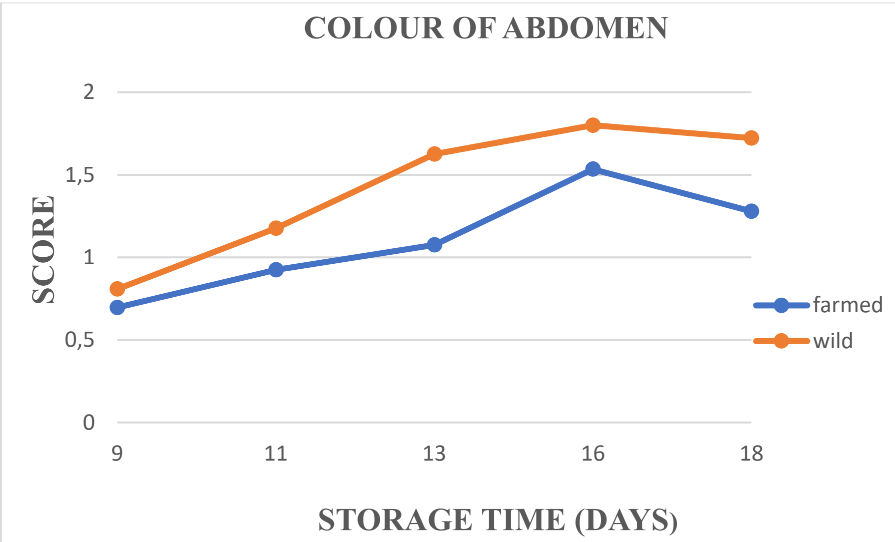

Figure 7. Changes in the average score of the abdominal colour with increasing storage time**.**

Figure 8 shows a graph of the average texture score versus storage time. The scores for wild-caught tilapia were slightly higher between days 9 and 13, where the scores were the same for both groups. At the time of evaluation, no fish was in rigor which indicated freshness, and if a finger left a mark over 3 seconds.

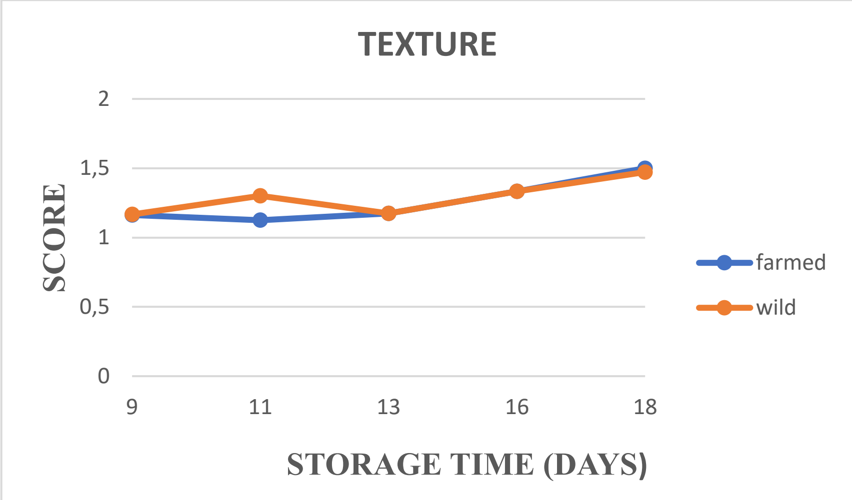

Figure 8. Changes in the average texture score with increased storage time.

Figure 9 shows a graph of the average score of the colour of the cornea against storage time. An opaque and cloudy cornea indicated reduced freshness, whereas a clear and transparent cornea indicated freshness. The scores for both groups increased linearly up to day 16 and then became constant between days 16 and 18. This means that most of the sensory changes in the colour of the cornea happened between days 0-16 days.

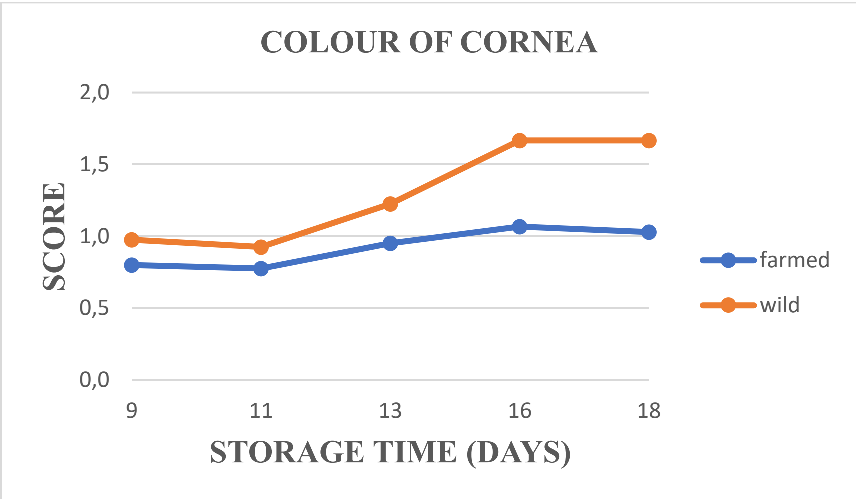

Figure 9. Change in the average score of the colour of the cornea with an increase in storage time.

Figure 10 shows a graph of the average score of the colour of the pupil against storage time. As days increased, the average scores of the colour of the pupil also increased for wild caught, whereas the scores for farmed tilapia were almost constant throughout. Dull grey indicated reduced freshness and bright black indicated freshness.

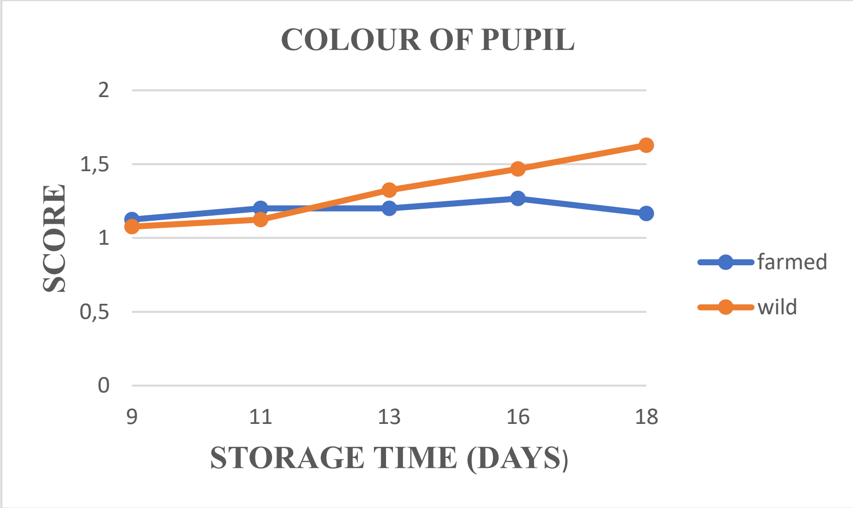

Figure 10. Changes in the average score of the colour of the pupil with increased storage time.

Figure 11 shows the average scores of the form of the eye against storage time in days. Initially, between days 9 and 11, scores increased gradually for both groups, with a greater increase for wild tilapia, and then gradually decreased to scores between 1.6 and 1.5, and both groups stagnated. This is different from the other attributes that were changing. This behaviour can be attributed to the description of the form. When the scale described convexity as an indicator of freshness, most assessors found it difficult to describe it as it was only slightly convex. In addition, changes in the eyes occur in the early stages of storage which were missing in this study.

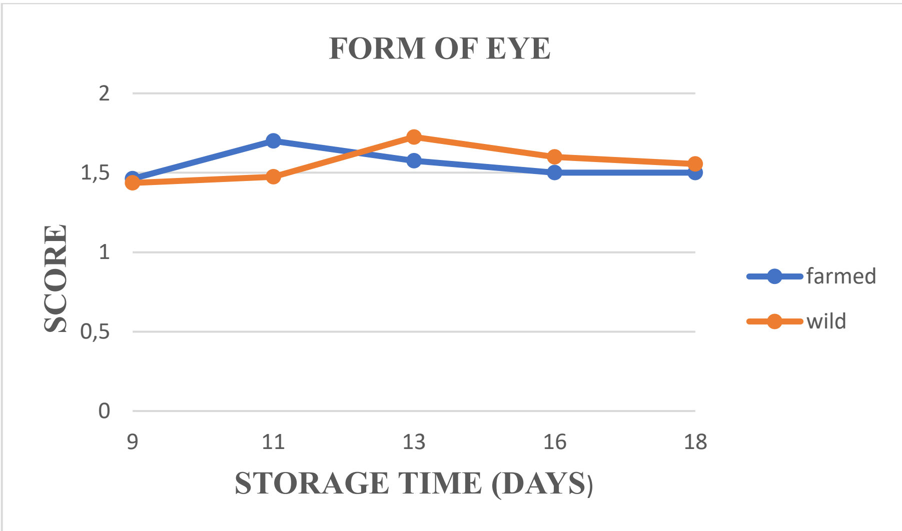

Figure 11. Average score of eye shape changed with increased storage time.

Figure 12 shows a graph of the average scores of appearance/colour of gills against storage time in days. Bright red to violet indicates freshness, whereas discoloration to brown indicates reduced freshness. The scores for wild-caught tilapia were generally higher than those for farmed tilapia, with a gradual increase in scores for both groups as storage time increased.

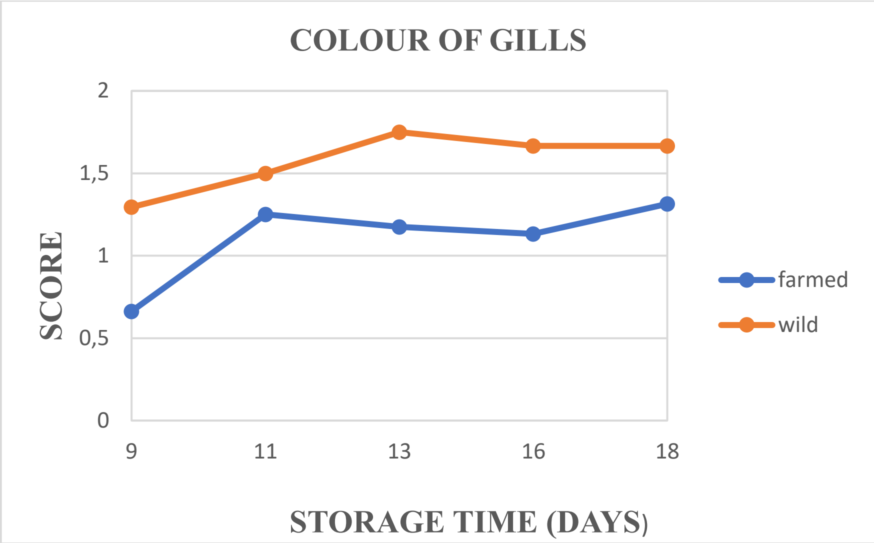

Figure 12. Average score of gill colour as a function of storage time.

Figure 13 shows a graph of the average mucus scores against storage time. Transparent and not sticky was an indicator of freshness, whereas milky, sticky, and brown indicated reduced freshness. There was a steep increase between 9 and 11 days, followed by a linear increase up to day 18 for wild caught tilapia as storage time increased. In the case of farmed tilapia, there was a sharp increase between days 9 and 11, which decreased slightly up to day 16, where it increased again. This behaviour was because some farmed fish had mucus which was not sticky in the initial days, but the mucus later became brown.

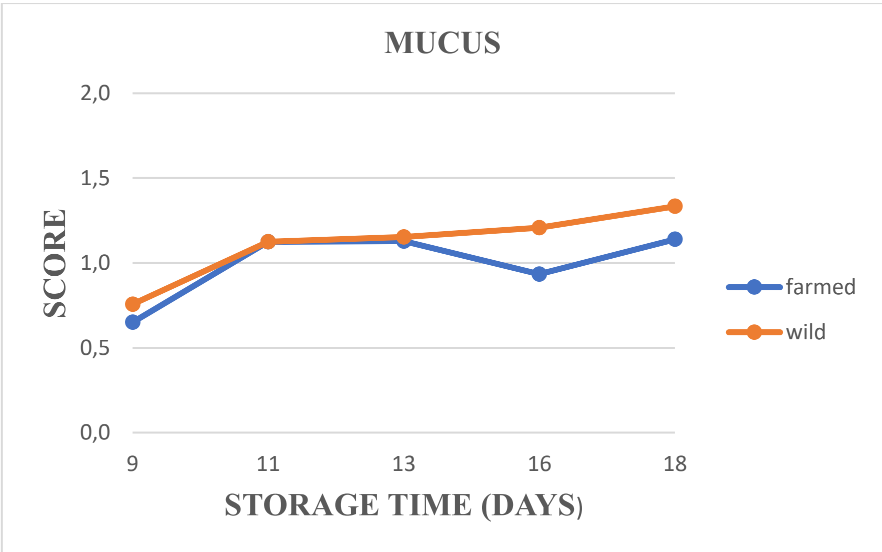

Figure 13. Average mucus score changes with increased storage time.

Figure 14 shows the average score of gill odour against storage time in days. As storage time increased, the mean scores increased for both groups, with a higher score recorded for wild-caught tilapia. Fresh seaweed smell was recorded as an indicator of freshness, whereas rancid smell indicated reduced freshness. However, while rancid was indicated as an indicator of reduced freshness, most panellists reported sourness as an indicator of spoilage as storage time increased, suggesting that changes should be made to that effect. This is in line with the findings of Vazquez et al. (2020), who determined that a sour or rotten smell of gills is an indicator of reduced freshness.

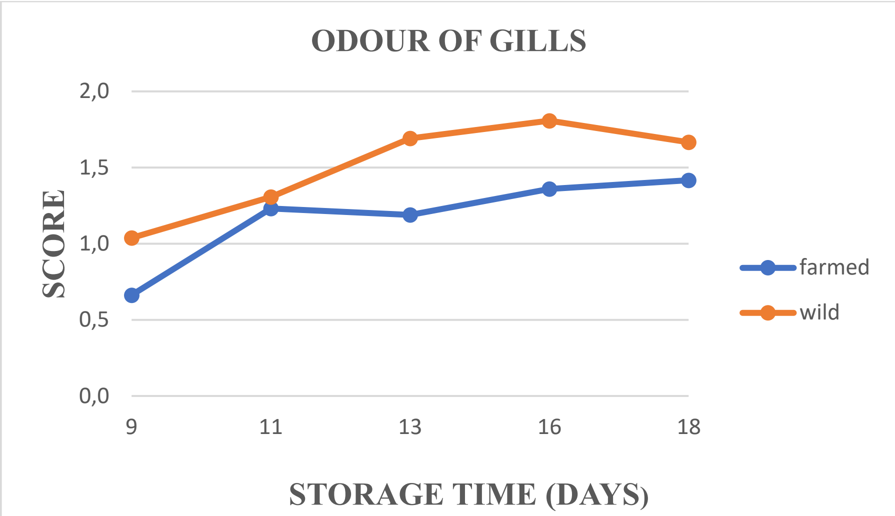

Figure 14. Changes in the average score of gill odour with increased storage time.

Figure 15 shows the average scores of the internal abdominal walls against the storage time. Immediately after harvesting, the internal abdominal walls were bright silver with black dots which is an indicator of freshness. However, as the storage time increased, the internal walls became less bright, and a dull yellowish colour developed, indicating reduced freshness of the tilapia. From Figure 15, we can see that the scores increased linearly as the storage days increased.

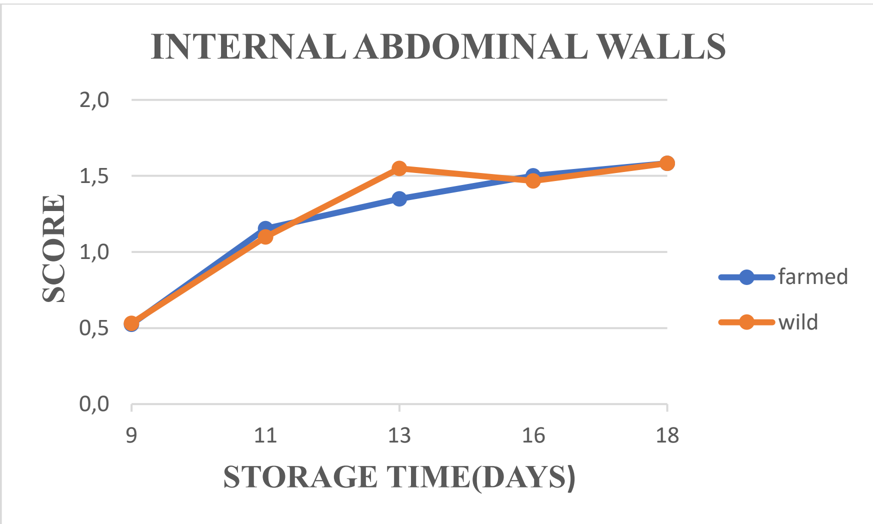

Figure 15. Average score of internal abdominal walls with increase in storage time.

Figure 16 shows a graph of the blood colour scores against storage time. Initially, the scores increased between days 9 and 11 from 0.4 to 1.8 for wild-caught tilapia and from 0.2 to 0.8 for farmed tilapia, and it started declining for both groups until the last day of sampling. This is contrary to the findings of Martinsdottir et al. (2001), who reported that the scores of an attribute are expected to keep increasing as storage time increases. According to the scale, bright red or absence of blood is an indicator of freshness, whereas dark red to brown blood indicates reduced freshness or spoilage. However, blood was only present in the first two sampling sessions and later diffused, which is why this was attributed to reduced scores.

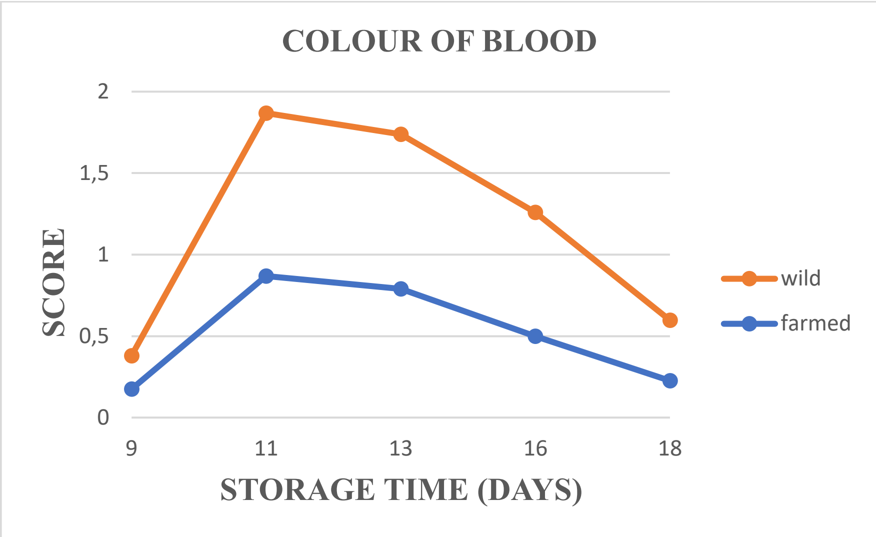

Figure 16. Average score for blood colour changes with increased storage time.

In general, the quality parameters describing the different levels of freshness from the QIM are skin brightness, abdomen colour, texture, cornea colour, pupil colour, eye form, gill colour, mucus, odour, internal abdominal wall, and blood colour. All these parameters were evaluated in five sessions during the study, and none of the groups reached a maximum score at the end of the storage time, as shown above. According to Martinsdottir et al. (2001), a QIM scheme is constructed such that a fish evaluated after harvest receives a low score, but the score subsequently increases with storage time, reaching almost the maximum score at the end of the fish's shelf life. However, while evaluating, some challenges and difficulties were encountered for some of the attributes. The description of the form of the eyes, evaluation of the intestinal abdominal walls, and the odour of the gills were highlighted. It was not easy to describe the intestinal walls of mainly wild caught fish because the fish were not well sliced, making it difficult to see inside the internal walls. The shape of the eye was convex on the scale, but in reality, the eyes were slightly convex, suggesting an improvement in the scale. For the odour of gills, rancid was indicated as a spoilage indicator, however, most panellists reported sour as the odour of the fish as storage time increased. The presence of blood in the abdomen was indicated as a freshness indicator; however, blood was only present during the first ten days after harvest, after which it diffused. This affected the final QI score. It was suggested that the QIM scale be improved, where the absence of blood is an indicator of reduced fish freshness. Notably, no attribute had a score of zero. This was because the first evaluation was performed on the 9th day when freshness had started to reduce.

QI score throughout storage

Table 8 shows the change in the average QI for each day of sampling for both farmed and wild-caught tilapia. The results for wild-caught tilapia were higher than those for farmed tilapia, with a significant difference ($P<0.05$). Based on the results, it was evident that the panellists found it difficult to differentiate between samples of 13, 16, and 18 days, the time when panellists had started noticing undesirable/negative attributes. Similar results were reported by Vazquez et al. (2020) and Rodrigues et al. (2015), who showed that tilapia displayed optimal quality until day 10 of storage, after which it started developing characteristics attributed to the loss of sensory qualities. However, the difficulty in differentiating between the characters on days 13, 16, and 18 can also be attributed to the shorter sampling points.

Table 7. QIM evaluation with SD for farmed and wild-caught fish showing changes over increased storage time.

Storage time (days)	Farmed tilapia	Wild caught tilapia
9	8.36 ± 3.19	9.96 ± 2.97
11	12.00 ± 3.11	13.23 ± 3.60
13	12.28 ± 4.55	15.55 ± 3.13
16	13.11 ± 4.12	16.07 ± 3.22
18	13.23 ± 4.44	16.30 ± 2.82

The results are shown in Figure 17.

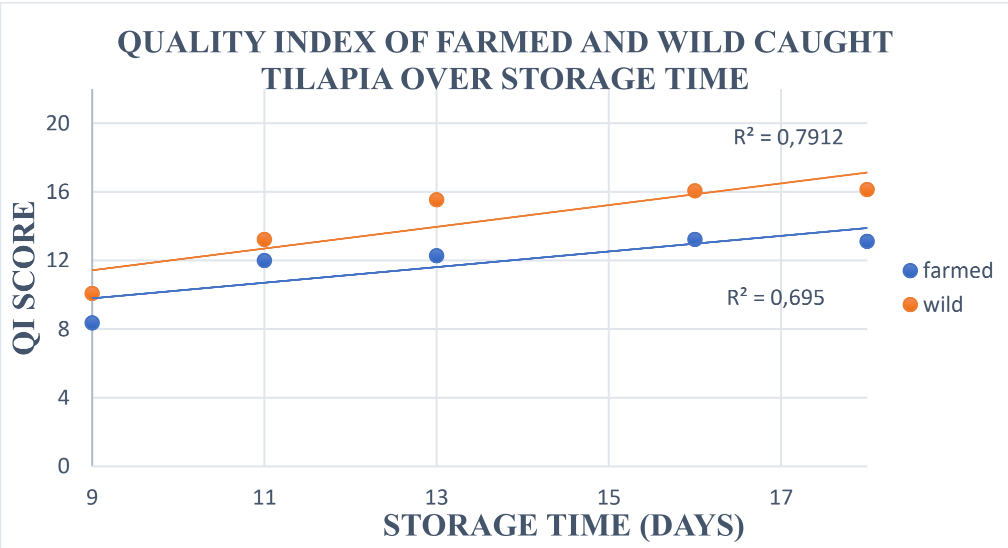

Figure 17. Graph of the linear relationship between the quality indices of farmed and wild-caught tilapia and storage time.

After exclusion of data from panellists P-3 and P-10, the remaining panellists (n=8) evaluated replicated samples (n=5) for all the sample groups (farmed and wild caught). The sum of the individual parameter scores evaluated according to the QIM scheme is presented as QI. QI showed a linear relationship with storage time in both groups. A stronger linear correlation of $R^2 = 0.829$ was observed for wild caught tilapia. However, the linear relationship between the QI and storage time for farmed tilapia was as strong as that of wild caught tilapia $R^2 = 0.726$.

These results show that the attributes used clearly described the loss of freshness of tilapia from both groups stored on ice. From the graph, it is clear that there is a difference between farmed and wild-caught tilapia.

The study results suggested modifications to the QIM scheme, removing or adjusting the description of the attribute "Blood in abdomen". Removing it provides better linearity in the QIM scheme, both when evaluating wild and farmed fish separately and all data together, as shown in Figures 27 and 28 in the Appendix.

4.5.2 GDA results

The panellists evaluated the cooked tilapia flesh based on sensory attributes for cooked tilapia during the training session, as described in Table 9. The results for each attribute are presented as averages of the entire sensory panel (seven to eight panellists per trial). The GDA attributes for cooked tilapia were described based on a scale ranging from 0 to 100.

The sensory quality attributes of cooked tilapia detectable at the beginning of storage time or immediately after harvest are considered freshness (positive) attributes, as they are indicators of freshness, whereas attributes detectable at the end of storage time are considered spoilage (negative) attributes, as they are indicators of spoilage (Cyprian et al., 2008; Sveinsdottir et al., 2002). The freshness attributes were sweet, metallic, hot milk, boiled potatoes, and arctic charr, while the spoilage attributes were sour, TMA, spoilage, and bitter tastes. The average GDA score of above 20 (on a scale of 0 to 100) for these attributes indicates spoilage, which indicates that the fish is unacceptable for human consumption.

Freshness attributes were higher in farmed fish than in wild-caught tilapia. On day 11, these values were higher but reduced on day 16, indicating reduced freshness. Although these freshness attributes were higher for farmed tilapia, they did not significantly change, except for boiled potatoes. Similarly, spoilage attributes were higher for wild-caught tilapia than for farmed tilapia. Spoilage was low on day 11 but increased on day 16, indicating reduced freshness. Musty or earthy odours and flavours originate from chemicals in fish feed, such as geosmin. Wild-caught tilapia has a much more musty and earthy odour and flavour which is not due to spoilage but rather the feed, mainly from algae and cyanobacteria which is abundant in the lake (Percival et al., 2008; Yarnpakdee et al., 2014).

Table 9. Results of GDA evaluation of farmed and wild caught tilapia on days 11, 16, and 17.

Group	odour							flavour								
day 11	musty	earthy	potatoes	milk	sour	TMA	spoilage	charr	earthy	sweet	metallic	musty	sour	bitter	TMA	spoilage
FARMED	10	13	38	27	4	10	11	19	24	26	16	15	8	6	4	6
WILD	46	26	15	9	7	5	25	6	23	13	16	40	9	12	4	9
p-value	0,021	0,102	0,033	0,081	0,171	0,116	0,304	0,165	0,910	0,021	0,962	0,043	0,616	0,340	0,812	0,324
day 16																
FARMED	14	23	28	12	5	10	14	16	37	18	14	7	8	11	10	11
WILD	28	28	20	8	11	6	31	13	35	15	15	21	12	15	13	27
p-value	0,057	0,518	0,108	0,256	0,347	0,170	0,096	0,060	0,820	0,435	0,820	0,270	0,234	0,413	0,128	0,169
day 17 ice																
FARMED	12	12	30	15	5	16	18	18	23	16	17	12	7	11	13	19
WILD	38	22	24	13	5	21	26	13	22	7	12	26	10	16	21	24
p-value	0,051	0,063	0,046	0,611	0,676	0,142	0,295	0,484	0,900	0,146	0,001	0,280	0,568	0,354	0,326	0,475

The odour and flavour attributes are graphically represented below, where O- represents odour and F represents flavour (Figures 18–26).

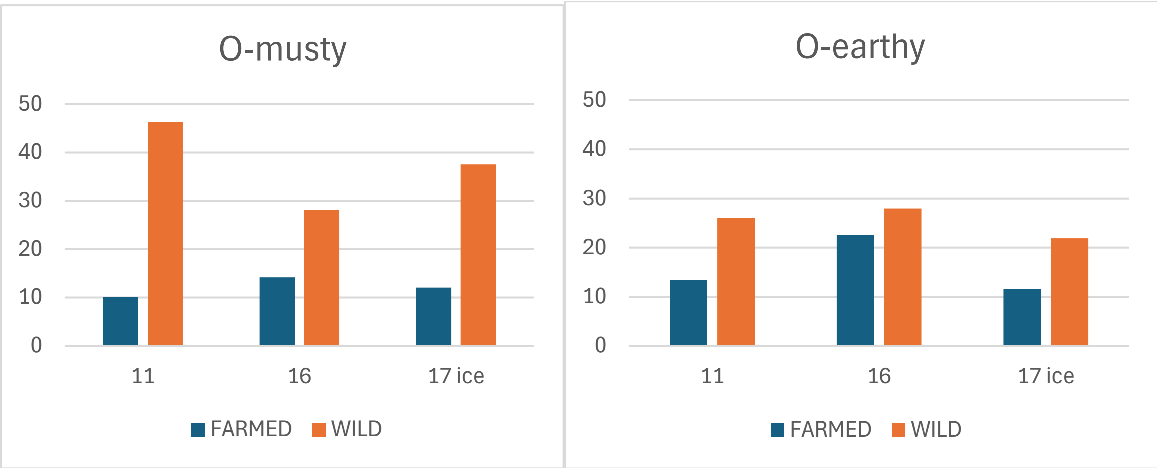

Figure 18. Changes in musty and earthy odours on days 11, 16, and 17.

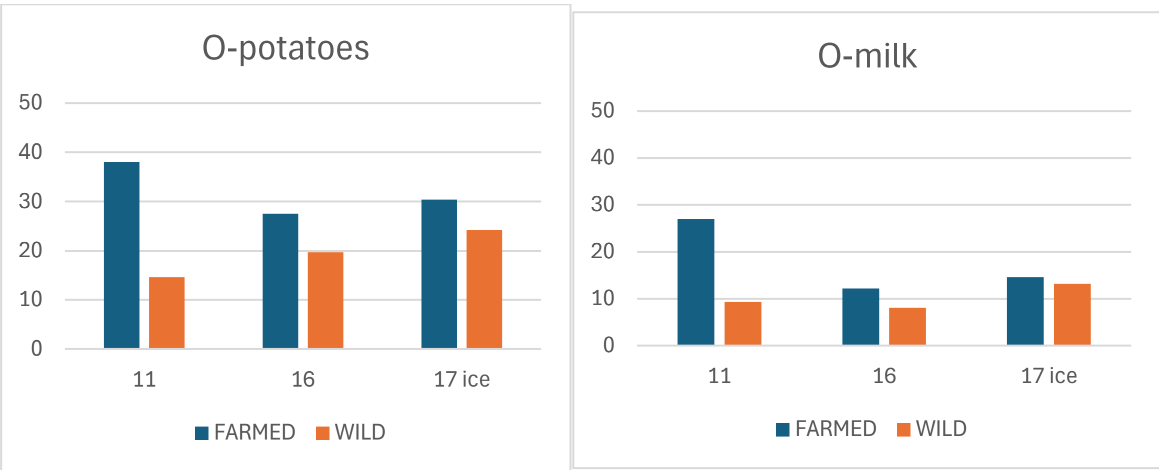

Figure 19. Changes in potato and milk odours on days 11, 16, and 17.

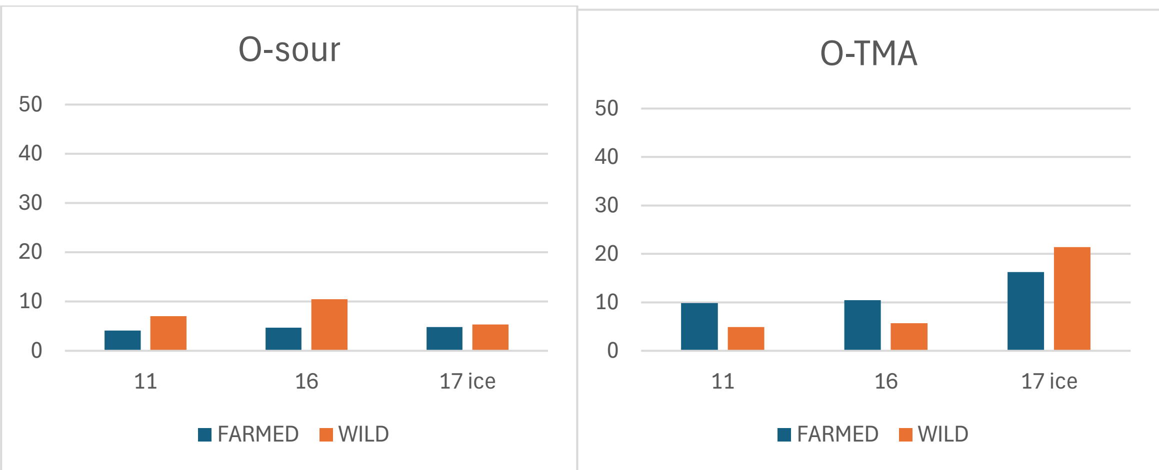

Figure 20. Changes in sour and TMA odour for days 11, 16, and 17.

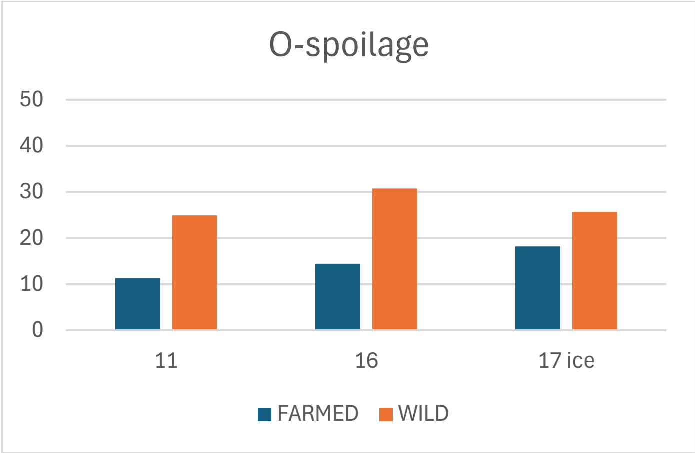

Figure 21. Changes in spoilage odour on days 11, 16, and 17.

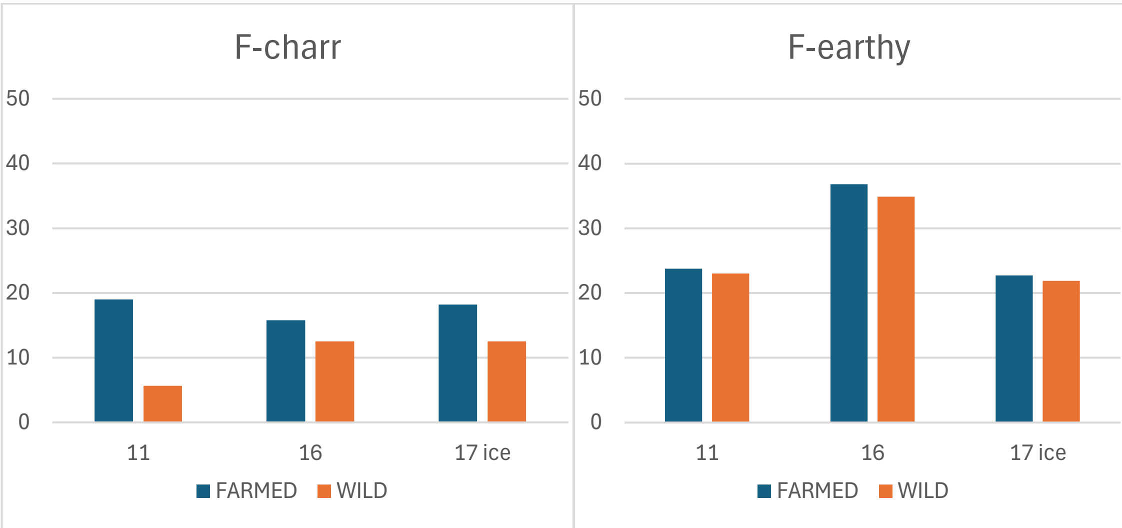

Figure 22. Changes in charr and earthy flavours on days 11, 16, and 17.

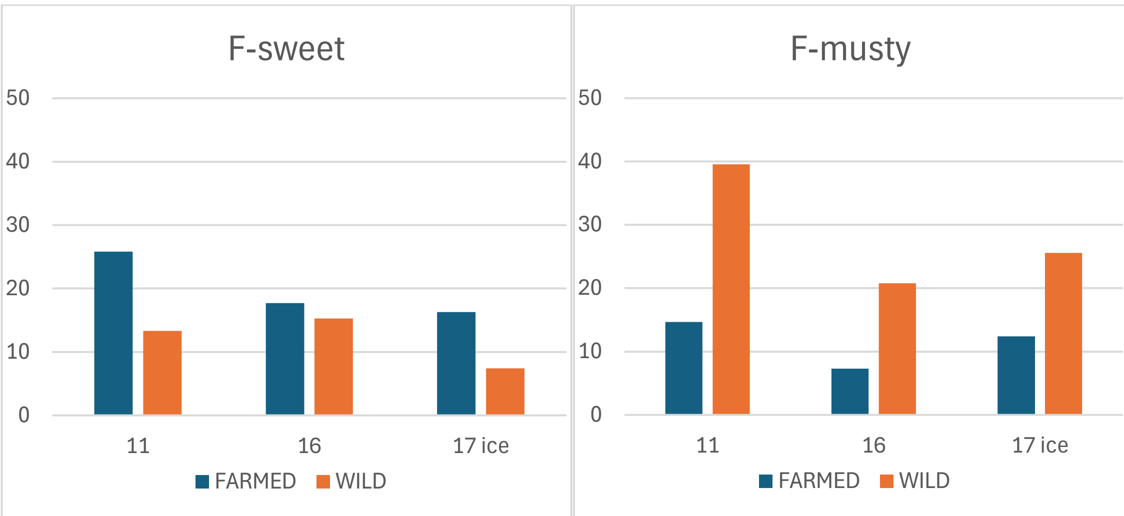

Figure 23. Changes in sweet and musty flavours on days 11, 16, and 17.

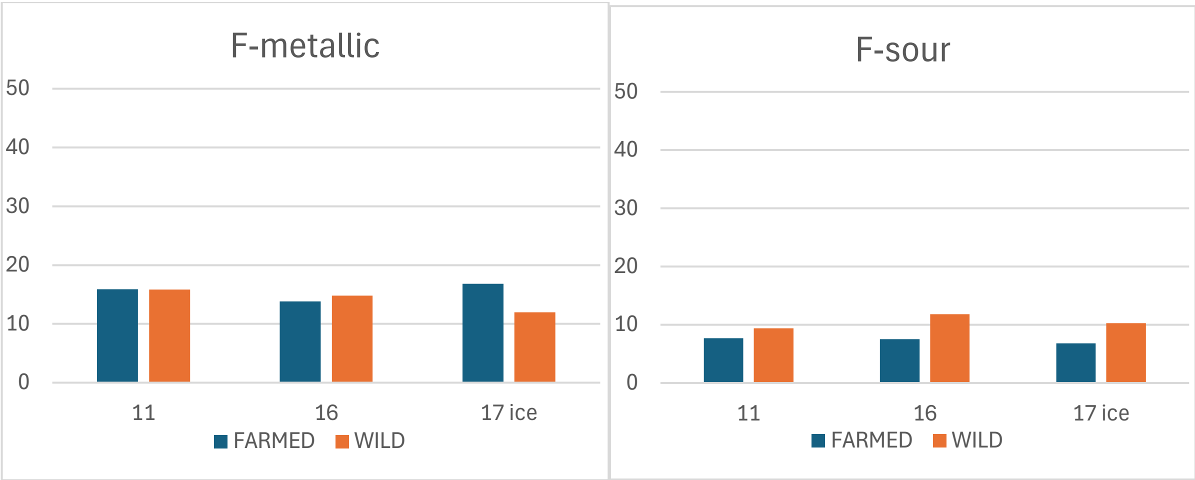

Figure 24. Changes in metallic and sour flavours on days 11, 16, and 17.

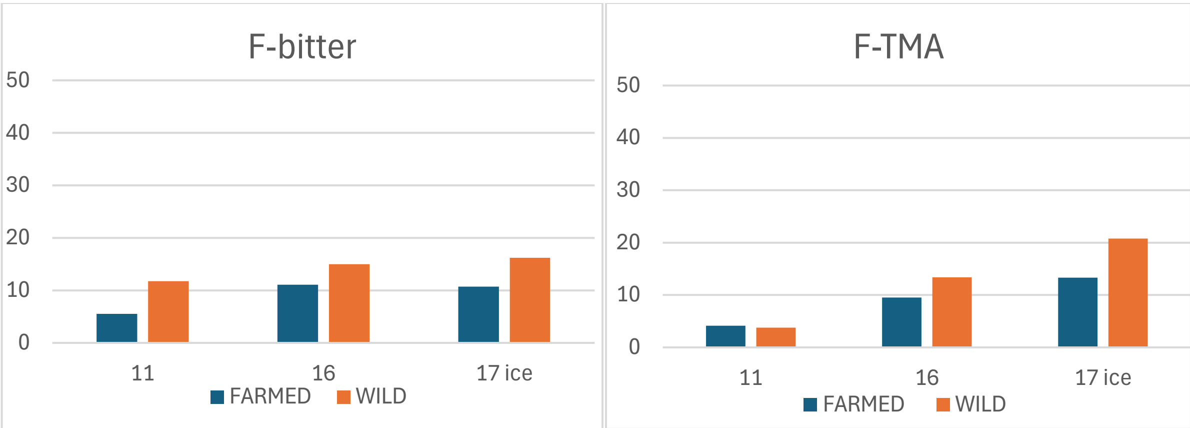

Figure 25. Changes in bitter and TMA flavour for days 11, 16, and 17.

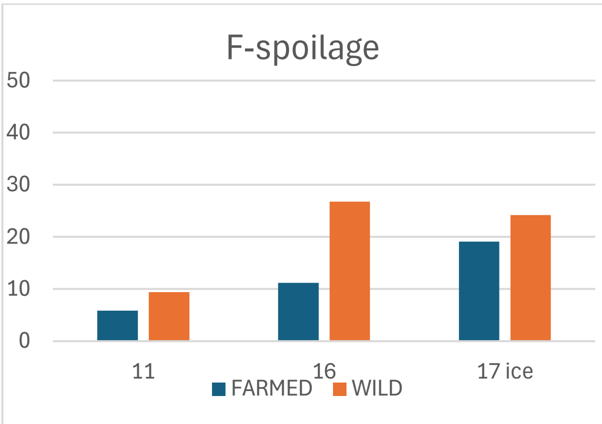

Figure 26. Changes in spoilage flavour on days 11, 16, and 17.

4.5.3 Correlation between QIM and GDA results.

Comparing the QIM results and GDA, it can be noticed that wild-caught tilapia loses its sensorial quality faster than farmed tilapia. The QI scores for wild-caught tilapia were higher than those for farmed tilapia. Similarly, the scores for individual attributes were all higher than those of farmed tilapia. For GDA, the positive attributes were higher in farmed tilapia, whereas the negative attributes were higher in wild-caught tilapia. These results are consistent with the findings of the QIM scheme.

5 CONCLUSION AND RECOMMENDATIONS

In the current study, the QIM scheme proposed by Rodrigues *et al*. (2015) was used. The revised QIM scheme had 11 parameters which gave a total of 22 demerit points. The scores for quality attributes included in the QIM scheme increased differently with storage time for farmed and wild-caught tilapia, but they all showed a fair linear relationship between QI and storage time, with a significant correlation in all sample groups. This shows that the developed QIM scheme can be used to estimate the storage time of both farmed and wild-caught tilapia. Suggestions were made to further improve the QIM scheme's performance. Sour was suggested as a spoilage indicator of gills odour instead of rancid. Furthermore, the lack of blood was suggested as an indicator of spoilage instead of freshness, as had been indicated by the QIM. The consistently high scores when evaluating the eyes were due to the fact that most of the quality changes in the eye happen during the early stages of storage which was lacking in this study. At the end of the study, the QIM scheme was revised to capture these additions. No blood was instead named as spoilage attribute and sour replacing rancid as spoilage attribute for odour of gills, as shown in Table 10 in the Appendix.

The GDA results showed that freshness attributes were higher in farmed tilapia, whereas spoilage attributes were more prominent in wild-caught tilapia than in farmed tilapia. This is contrary to the existing perceptions among consumers in Uganda. The higher undesired attributes (spoilage) may be due to post-harvest handling of wild-caught tilapia, where temperature abuse is common. Icing occurs when the fish arrive at the gazetted landing site. Most landed fish (tilapia) appear to have been held over a long period between catching and landing in open small boats, often without ice, where plant fibre, woven baskets, and gunny bags are thought to prevent direct heating of the fish by the sun, thereby diminishing the rate of bacterial decomposition. These post-catch fish treatments may result in cross-contamination of microbes from the handling equipment to the fish, as they do not conform to good hygiene and fish handling practices.

Wild-caught tilapia consistently exhibited musty and earthy flavours, as well as a musty flavour. Earthy aroma in fish is associated with the presence of geosmin (GSM) and/or 2-methyl-isoborneol (2-MIB), which are metabolites produced by algae and cyanobacteria found in freshwater systems, such as Lake Victoria. Earthy odour and flavour taints are commonly reported in other fish species produced in freshwater systems. This may partly explain why most tilapia consumers in Uganda prefer wild-caught tilapia over farmed tilapia, as most consumers are used to this earthy or musty odour and flavour which is more abundant in wild tilapia than in farmed tilapia.

The lack of many statistical differences based on the examined sensory attributes, despite the large margins recorded, may be attributed to the fact that panellists evaluated samples differently. This may be due to limited training of the panellists, and changes may occur in the early stages of storage which was lacking in the study.

In recommendation, the current study was conducted 9 days after harvest; therefore, the results may be lacking changes that occur during the early stages of storage. This could suggest why some attributes had higher scores at the beginning of the study and why others had scores which were almost constant. Further studies should be conducted to identify changes that occur in the early stages of storage.

The current study revealed that farmed tilapia had higher fat content and better fillet yield percentages than wild-caught tilapia. However, the moisture content of wild-caught tilapia was higher than that of farmed tilapia. This shows that farmed tilapia had a better proximate composition than wild-caught tilapia.

The current study demonstrated that farmed and wild-caught tilapia have comparable sensory qualities. Although consumers tend to prefer wild tilapia over farmed tilapia in Uganda, the current study suggests that this preference may be based on factors other than the objective sensory qualities of the fish. More sensitisation and public awareness are needed to clear misconceptions about the quality of farmed tilapia.

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APPENDIX

The photos show how the farmed and wild caught tilapia changed with increased storage time.

Storage time	**Farmed tilapia**	**Wild tilapia**
9	Whole tilapia 	Whole tilapia 
	Eyes 	Eyes 

	Gills 	Gills 
	Internal abdominal walls 	Internal abdominal walls 
11	Whole tilapia	Whole tilapia 

		
	Eyes 	Eyes 

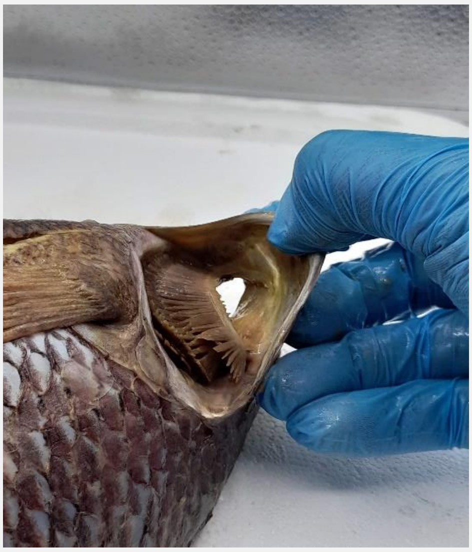
	Gills 	Gills 
	Internal abdominal walls 	Internal abdominal walls 

13	Whole tilapia 	Whole tilapia 
	Eyes 	Eyes 
	Gills 	Gills 

	Internal abdominal walls 	Internal abdominal walls 
16	Whole tilapia 	Whole tilapia 

	Eyes 	Eyes 
	Gills 	Gills 
	Internal abdominal walls 	Internal abdominal walls 

18	Whole tilapia 	Whole tilapia 
	Eyes 	Eyes 

	Gills 	Gills 
	Internal abdominal walls 	Internal abdominal walls 

Final QIM scheme

Table 8. The final QIM scheme for tilapia with revised quality attributes as recommended by different panellists.

Quality parameter		Description	Points
Overall appearance	Skin brightness	Iridescent/bright	0
		Less bright	1
		Dull	2
	Colour of abdomen	White, pink, no yellow colour	0
		Slightly yellowish	1
		Yellowish	2
	Texture	In Rigor	0
		Finger mark disappears rapidly	1
		Finger leaves mark over 3 seconds	2
Eyes:	Colour of cornea	Transparent, clear	0
		Slightly cloudy	1
		Cloudy, opaque	2
	Colour of pupil	Bright black	0
		Slightly grey and dull	1
		Dull grey	2
	Form	Convex	0
		Flat	1
		Concave	2
Gills:	Colour/ appearance	Bright red to violet	0
		Less-bright red/ red brown	1
		Discoloured/ brown	2
	Mucus	Transparent, not sticky	0
		Slightly milky, and sticky	1
		Brown, clotted	2
	Odour	Fresh, seaweed	0
		Slightly metallic	1
		Sour	2
Abdomen:	Internal abdominal wall	Bright silver colour with black dots	0
		Less bright with black spots	1
		Dull, yellowish, with black dots	2
	colour of blood	Bright red	0
		Dark red	1
		Brown or not present	2
Quality Index (0 - 22)			

Fatty acid analysis.

Table 9. Detailed fatty acid composition analysis for farmed and wild caught tilapia.

FATTY ACIDS	WILD			FARMED		
	1CA	2CA	3CA	1FA	2FA	3FA
Saturated fatty acid						
C12:0	0,14					
C14:0	3,96	1,73	2,49	2,88	3,43	2,57
C15:0	0,35	0,23	0,29			
C16:0	24,72	22,77	24,27	25,72	30,73	24,34
C17:0	0,56	0,39	0,49			
C18:0	7,26	8,17	7,62	6,44		6,38
C23:0	5,75	10,45	7,28	6,13	6,87	6,09
∑SAF	**42,74**	**43,74**	**42,44**	**41,17**	**41,03**	**39,38**
Monounsaturated fatty acid						
C14:1	0,43		0,19			
C15:1	0,23		0,11			
C16:1n7	6,31	4,57	5,34	4,94	5,84	4,46
C18:1n9	12,97	8,52	9,35	28,8	24,25	25,83
C18:1n7	3,96	4,07	4,11	2,69	1	2,81
C20:1n11	0,72	0,37	0,37	1,32	1,48	1,17
C20:1n9	0,3	0,11	0,1	0,15	0,18	0,12
C22:1n(11+9)	0,25	0,3	0,23	0,11	0,12	0,13
∑MUFA	**25,17**	**17,94**	**19,8**	**38,01**	**32,87**	**34,52**
Polyunsaturated fatty acid						
C16:2n4	1,11	1,01	1,52	0,24	0,28	0,34
C16:3n4	0,21					
C18:2n6	3,04	2,46	3,64	13,34	16,17	14,77
C18:3n4	3,17	2,98	4,68	1,45	1,66	1,96
C18:3n3	1,56	0,25	0,46	0,25	0,29	0,36
C20:2	0,33	0,45	0,47	0,82	0,98	0,8
C20:3n6	2,69	4,79	3,05	1,57	1,9	1,44
C20:4n3	0,66	0,46	0,55			0,61
C20:5n3 (EPA)	2,67	3,92	3,44	0,33	0,38	
C22:4n6	0,25	1,62	0,89	0,92	1,11	0,72
C22:5n3	3,54	5,53	5,08	0,79	0,94	1,26
C22:6n3 (DHA)	9,78	17,64	11,82	2,97	3,58	4,93
C18:3n3		0,77	0,76	0,18	0,21	0,28
∑PUFA	**29,01**	**41,88**	**36,36**	**22,86**	**27,5**	**27,47**

Quality index without "blood in abdomen attribute."

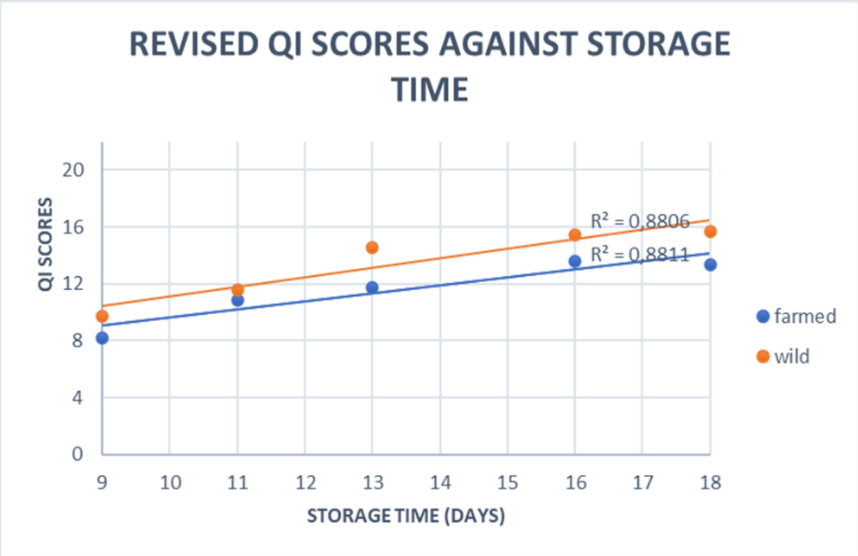


Figure 27. How QI scores changed with increasing storage time without results of "blood in abdomen" attribute for farmed and wild caught tilapia.

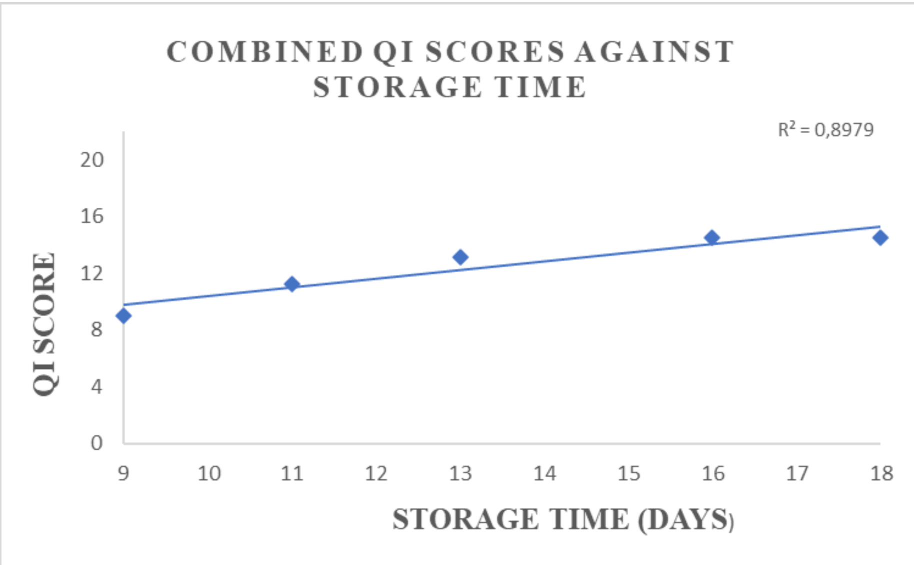


Figure 28. How combined QI scores changed with increasing storage time without results of "blood in abdomen" attribute.