

Effects of cantaloupe (*Cucumis melo* L. cv. Sun Lady) processing by-products on growth performance, pigmentation and skin mucosal lysozyme activity of goldfish (*Carassius auratus*)

¹Panisara Wongrak, ¹Petlada Petchu, ¹Kanlayanee Assana, ¹Nanthavich Suanyamo, ¹Tanaphat Rakwong, ^{1,2}Patiwat Rodtongsan, ^{1,2}Niracha Ratdee, ^{1,2}Dame Korn, ^{1,2}Akkarawit Issaro, ^{1,2}Nutt Nuntapong

¹ Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University Hat Yai Campus, Songkhla, 90110, Thailand; ² Kidchakan Supamattaya Aquatic Animal Health Research Center, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University Hat Yai Campus, Songkhla, 90110, Thailand. Corresponding author: N. Nuntapong, nutt.n@psu.ac.th

Abstract. The circular economy is an important concept for the agricultural and food industries, as it focuses on resolving waste disposal and recycling challenges to mitigate environmental and sustainability concerns about natural resources. The fruit processing industry generates substantial waste, accounting for up to 8% of total food waste. To reduce waste produced by fruit-industrial processes, a 52-day feeding experiment was conducted to evaluate the effects of different dietary cantaloupe (*Cucumis melo* L. cv. Sun Lady) processing by-products (CPP) on the growth performance, pigmentation, and skin mucosal lysozyme activity of goldfish (*Carassius auratus*). Juvenile healthy goldfish (initial weight 5.43 ± 0.07 g) were distributed into four treatment groups with 3 replications and fed with four isonitrogenous (400 g kg^{-1}) and isolipidic (100 g kg^{-1}) diets supplemented with CPP: 0 (control), 25, 50, and 100 g kg^{-1} diet. The results indicated that fish fed diets supplemented with 25 or 50 g kg^{-1} CPP exhibited significant improvements in the final body weight and specific growth rate (SGR) compared to the control ($p < 0.05$). Quadratic regression analysis of SGR in relation to dietary CPP levels suggested that the optimal dietary CPP supplement level for maximizing growth performance was at 55 g kg^{-1} . The protein efficiency ratio of fish fed the CPP 25 g kg^{-1} diet was significantly ($p < 0.05$) higher than that of fish fed the control diet and CPP 100 g kg^{-1} diet but not significantly ($p > 0.05$) different from that of fish fed the CPP 50 g kg^{-1} diet. There were no significant differences in feed conversion ratio, feed intake, and survival rate noticed among fish fed the experimental diets ($p > 0.05$). The CPP supplementation improved the redness (a^*) and yellowness (b^*) color coordinates of goldfish compared to the control ($p < 0.05$), whereas skin lightness (L^*) did not seem to be influenced by dietary inclusion of CPP ($p > 0.05$). Quadratic regression analysis of a^* in relation to dietary CPP levels suggested that the optimal dietary CPP supplement for maximizing pigmentation was at 91 g kg^{-1} . Goldfish in all experimental treatments supplemented with various levels of CPP exhibited significantly elevated skin mucosal lysozyme activity compared to the control group ($p < 0.05$), indicating a higher immunity status of the fish. In conclusion, this study revealed that supplementation of CPP at 55 g kg^{-1} maximally promotes growth performance, and at 91 g kg^{-1} it greatly enhances pigmentation in goldfish. The dietary supplementation of CPP also has the potential to be an immune enhancer because of an increase in skin mucosal lysozyme activity. These findings provide a potential use for CPP as a functional feed ingredient for goldfish and other ornamental fish species.

Key Words: aquatic feed, cantaloupe by-products, circular economy, coloration, goldfish.

Introduction. The FAO (2023) stated that global fruit production in 2021 was estimated at 0.95 billion tons, accounting for 10% of the total major crop production of 9.5 billion tons in that year. Generally, consumers prefer to consume fresh fruits due to the unique taste of each fruit, freshness, and nutritional values beneficial to health. As a result, the fresh fruits market volume is expected to reach 319.90 billion kg by 2030 and is projected to grow at a compound annual growth rate (CAGR) of 6.4% from 2024 to 2030 (Statista 2025). In fact,

fruit processing by-products are typically generated in substantial quantities from direct consumption, during harvesting when fruits that do not meet the required marketing standards are discarded, and at the processing operations within the food processing industry (Wanapat et al 2024). Currently, fruit processing by-products account for approximately 57 million tons of global waste annually, posing economic, environmental, and food security challenges (Faulisi et al 2024). Approximately 37.5% of fruit processing by-products consist of peels produced by the juice processing sector, as well as garbage from restaurants and vendors, which is frequently discarded into the environment (Li et al 2020). Research studies indicate that the fruit processing by-products generated are a waste product having potential for utilization due to various beneficial compounds (Khan et al 2024). By 2030, the EU intends to decrease per capita global food waste and reduce food losses throughout production and supply chains. The EU can contribute to the achievement of the Sustainable Development Goals (SDGs) by reducing food losses and waste (United Nations 2024). Consequently, promoting the value of fruit by-products from the food processing sector under the principles of circular economy and zero waste, by exploiting the potential benefits of waste for suitable applications, represents an achievable possibility for implementing sustainable and eco-friendly practices (Scarano et al 2022).

The gourd family, belonging to the family Cucurbitaceae, is an important commercial crop, including cucumber, melon, watermelon, calabash, squash, and pumpkin (Schaefer & Renner 2011; Baloglu 2018). In 2023, approximately 29.54 million tons of melon and cantaloupe were produced worldwide (FAO 2025). Cantaloupe is one of the most popular types of gourd family cultivated in many countries, especially in temperate, subtropical, and tropical areas (Kesh & Kaushik 2021). The commercial processing of melons generates 8-20 million tons of waste (peels and seeds) annually globally (Rolim et al 2020). These wastes have potential for utilization, with reported applications in various fields, including as sorbents for the removal of heavy metals in water treatment (Hamdaoui et al 2010; Ahmad et al 2018), production of bioethanol (Rico et al 2023), and for conversion to food functional ingredients due to their rich content of beneficial compounds, including phytochemicals, phenolic compounds, carotenoids, pectin, and tannins (Fundo et al 2018; Gómez-García et al 2022).

Ornamental fish feeds are formulated to be cost-effective with promoting optimal growth, health benefits, and color improvement, with an emphasis on natural ingredients. Considering the advantageous characteristics of cantaloupe waste, and to reduce the waste produced by fruit-industrial processes, its application as a food additive is the most appropriate choice for the ornamental fish sector. Therefore, the objective of this study was to explore the potential use of cantaloupe (*Cucumis melo* L. cv. Sun Lady) processing by-products on growth performance, pigmentation and skin mucosal lysozyme activity of goldfish (*Carassius auratus*).

Material and Method

Preparation of cantaloupe processing by-product powder (CPP). Cantaloupe fruits at the optimal ripening stage for commercial purposes were purchased from a shopping mall in Songkhla, Thailand, during September of 2024. After washing with tap water and trimming off both ends of the fruits using a knife, the rinds were removed manually and cut into uniform pieces. Subsequently, the remaining fruits were cut in half and the membranes of seed cavity were detached from the seeds. The rinds and seed cavity membrane were dried at 60°C for 24 h in a hot air oven, pulverized with a commercial grinder to pass an 80-mesh sieve. Then, the rind and seed cavity membrane powder were mixed together in equal proportions (1:1, w/w), kept in airtight plastic bags, and stored in the refrigerator at -20°C until use.

Diet formulation and preparation. Four isonitrogenous (400 g kg⁻¹) and isolipidic (100 g kg⁻¹) experimental diets were formulated with CPP at levels of 0, 25, 50, and 100 g kg⁻¹. Fish meal and defatted soybean meal were used as the major protein sources, with fish oil as the lipid source and wheat flour as the carbohydrate source in the experimental diets. For each formulation, rice flour was adjusted in proportion to CPP to ensure a similar chemical

composition. In the preparation of the experimental diets, all dry ingredients were finely ground and sieved through an 80-mesh stainless steel sieve before mixing with fish oil using a HOBART machine (LEGACY®, OH, USA), and were then added with distilled water at 400 g kg⁻¹ to form the dough. The homogenized mixture was pelleted to approximately 3 mm diameter and then dried in a hot-air blower oven to below 100 g kg⁻¹ moisture at 50°C for 6 h. After drying, the pellets were kept in low-density polyethylene plastic bags and stored in a freezer at -20°C during the trial. The experimental diets were analyzed for proximal composition according to the standard methods of AOAC (1995), and the details are presented in Table 1.

Table 1
Formulations and proximate compositions of the experimental diets

<i>Ingredient (g kg⁻¹)</i>	<i>Experimental diet</i>			
	<i>Control</i>	<i>CPP 25 g kg⁻¹</i>	<i>CPP 50 g kg⁻¹</i>	<i>CPP 100 g kg⁻¹</i>
Fish meal	380	380	380	380
Defatted-soybean meal	300	300	300	300
Wheat flour	119	119	119	119
Wheat gluten	20	20	20	20
Vitamin and mineral premix ¹	10	10	10	10
Choline chloride	1	1	1	1
Di-calcium phosphate	10	10	10	10
Fish oil	60	60	60	60
Rice flour	100	75	50	0
Cantaloupe processing by-product powder (CPP)	0	25	50	100
<i>Proximate composition (g kg⁻¹ as fed basis, analyses of 3 batches of diet)</i>				
Moisture	100.53	99.05	109.07	102.93
Crude protein	408.64	403.73	407.82	404.99
Crude fat	103.08	103.43	107.78	105.48
Crude fiber	20.46	35.21	49.96	79.46
Crude ash	113.38	118.08	117.50	116.98
Gross energy (MJ kg ⁻¹)	18.54	18.52	18.50	18.47

Note: ¹ Vitamin and mineral premix (unit kg⁻¹ feed): Retinal (A) 7,000 IU; Cholecalciferol (D3) 3,000 IU; Tocopherol (E) 1,500 mg; Menadione sodium bisulfite (K3) 30 mg; Thiamine (B1) 25 mg; Riboflavin (B2) 20 mg; Pyridoxine (B6) 25 mg; Cobalamin (B12) 0.02 mg; Niacin 100 mg; Pantothenic acid 80 mg; Ascorbic acid (C) 200 mg; Biotin 1 mg; Folic acid 10 mg; Cu 25 mg; Fe 30 mg; Mn 30 mg; I 1 mg; Co 0.2 mg; Zn 100 mg; Se 0.35 mg.

Experimental fish and rearing conditions. The experiment was conducted from September to November 2024 at the facilities of the Kidchakan Supamattaya Aquatic Animal Health Research Center (KS-AAHRC), Faculty of Natural Resources, Prince of Songkla University. Healthy goldfish juveniles were obtained from a commercial ornamental fish farm located in Ratchaburi province, Thailand. During the acclimation period, the fish were reared in a 1,000 L cylindrical fiberglass tank for one week and were fed the control diet twice daily. After acclimatization, a total of 120 goldfish with an average body weight of 5.43±0.07 g were divided into four groups with three replicates of 10 fish each and randomly assigned to 12 glass aquaria of 56 L. The fish were fed by hand twice daily until visual satiation for 52 days. Uneaten feed and feces in each tank were siphoned every morning before feeding. Throughout the feeding trial period, all the experimental tanks were cleaned every day with a 75% water exchange to maintain the water quality in optimum condition. The water temperature was maintained at 27-28°C, dissolved oxygen was more than 6 mg L⁻¹, total ammonia nitrogen was less than 1 mg L⁻¹, and pH was maintained at 7.5-8.0. Preparation, rearing, care and handling of the goldfish in the present study were performed strictly under the 'Ethical Principles and Guidelines for the Use of Animals for Scientific Purposes', National Research Council, Thailand.

Growth performance and feed utilization. At the end of the feeding trial, all fish in each aquarium were fasted for 24 h before sampling and then were anesthetized with 50 mg L⁻¹ clove oil. Due to fish often exhibiting a loss of their vibrant coloration under stress, the skin color assessments were performed prior to weighing. After assessment of skin coloration, fish were weighed individually and counted for the calculation of survival rate (SR), average final body weight, specific growth rate (SGR), feed intake (FI), feed conversion ratio (FCR), and protein efficiency ratio (PER). Growth performance and feed utilization metrics of the reared fish were calculated as follows:

$$\begin{aligned}\text{Survival rate (\%)} &= (\text{final number of fish} / \text{initial number of fish}) \times 100 \\ \text{SGR (\% day}^{-1}\text{)} &= [(\ln \text{ final body weight (g)} - \ln \text{ initial body weight (g)}) / \text{days}] \times 100 \\ \text{FI (g fish}^{-1}\text{)} &= \text{feed consumed (g)} / \text{number of fish} \\ \text{FCR} &= \text{dry feed intake (g)} / \text{weight gain (g)} \\ \text{PER} &= \text{weight gain (g)} / \text{protein intake (g)}\end{aligned}$$

Skin color assessment. Prior to the final weighing, three fish per aquarium ($n = 9$ fish per treatment) were randomly collected, and skin coloration was measured using the portable color reader HunterLab MiniScan EZ (Hunter Associates Laboratory, Reston, VA, USA). Sampling sites for colorimetric experiments included measuring the color of the dorsal skin portion near the dorsal fin. The color parameters recorded were L^* , a^* , and b^* for lightness, redness, and yellowness, respectively, in accordance with the recommendation of the International Commission on Illumination (CIE 1976).

Skin mucus collection. Mucus sample collection and assay of lysozyme activity were performed according to the method as described by Azimirad et al (2016). After individual weighing, the fish were thoroughly washed and placed into sterile polyethylene bags containing 10 mL of 50 mM NaCl, then agitated back and forth to remove the skin mucus. The bags were gently shaken for roughly one minute. Freshly collected mucus samples were immediately transferred to 15 mL sterile centrifuge tubes and stored on ice. The samples were centrifuged (Beckman Coulter, Inc., Allegra X-30R, Germany) at $1500 \times g$ for 10 min at 4°C. The collected supernatant was kept in 1.7 mL microcentrifuge tubes and stored at -80°C for further use. Lysozyme activity was analyzed using a turbidometric assay. The suspension of 0.3 mg mL⁻¹ of lyophilized *Micrococcus lysodeikticus* (Sigma-Aldrich, MO, USA) in 40 mM sodium phosphate buffer at pH 6.2 was used as the substrate. A volume of 50 μ L of the mucus sample was mixed with the substrate in a flat-bottomed 96-well plate. The reaction was carried out at room temperature, and the absorbance at 450 nm was measured in kinetic mode every minute for a total of 50 minutes using a Multiskan™ GO microplate spectrophotometer (Thermo Fisher Scientific, USA). One unit of lysozyme activity was defined as reducing the absorbance by 0.001 per min (Ellis 1990), and results are reported in unit mL⁻¹.

Statistical analysis. Data were analyzed by one-way analysis of variance (ANOVA) using SPSS software (version 11.5 for Windows, SPSS Inc., Chicago, IL, USA). The arcsine square root transformation of percentage data was used. The differences between the treatment groups were analyzed by one-way ANOVA and Duncan's new multiple range test (with a significance level of 0.05), and the results are presented as mean \pm standard deviation (SD).

Results

Growth performance, feed utilization, and survival rate. The growth performance parameters, feed utilization, and survival rate of goldfish fed different concentrations of CPP for 52 days are presented in Table 2. Survival of goldfish ranged from 93.33 ± 5.77 to 100%, but it was not significantly ($p > 0.05$) different among the experimental diets. The average final weight and SGR were significantly higher ($p < 0.05$) in fish fed the CPP 25 g kg⁻¹ diet compared to those fed the control diet, but not significantly different ($p > 0.05$) from those of fish fed the CPP 50 g kg⁻¹ diet. No significant ($p > 0.05$) difference in FCR and feed intake were noticed among fish fed the experimental diets. The PER of fish fed

the CPP 25 g kg⁻¹ diet was significantly ($p < 0.05$) higher than that of fish fed the control diet and CPP 100 g kg⁻¹ diets but not significantly ($p > 0.05$) different from that of fish fed the CPP 50 g kg⁻¹ diets. Quadratic regression was used to estimate the optimum dietary CPP concentration in relation to growth performance (Figure 1). A model-based maximum at 55 g kg⁻¹ diet level CPP was estimated using the regression equation $y = -0.00007x^2 + 0.00770x + 0.72829$, $R^2 = 0.89774$, for the SGR of goldfish.

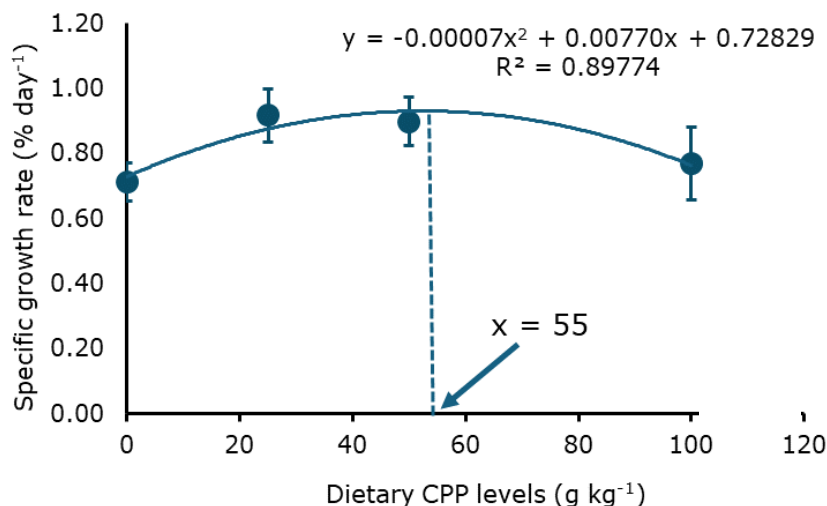


Figure 1. Polynomial regression analysis between specific growth rate and dietary CPP levels for goldfish.

Skin color parameters. The skin color parameters of goldfish fed different concentrations of CPP for 52 days are presented in Table 3. CPP supplementation exhibits improved redness (a^*) and yellowness (b^*) in the goldfish. The highest redness and yellowness ($p < 0.05$) were found in fish fed the CPP 100 g kg⁻¹ diet, followed by CPP 25 and 50 g kg⁻¹ diets, and the lowest was found in fish fed the control diet ($p < 0.05$). No significant differences were found in lightness (L^*) of fish among all the dietary treatments ($p > 0.05$). A model-based maximum at 91 g kg⁻¹ diet level CPP was estimated using the regression equation $y = -0.0007x^2 + 0.1279x + 22.43465$, $R^2 = 0.8845$ for the redness (a^*) of goldfish (Figure 2).

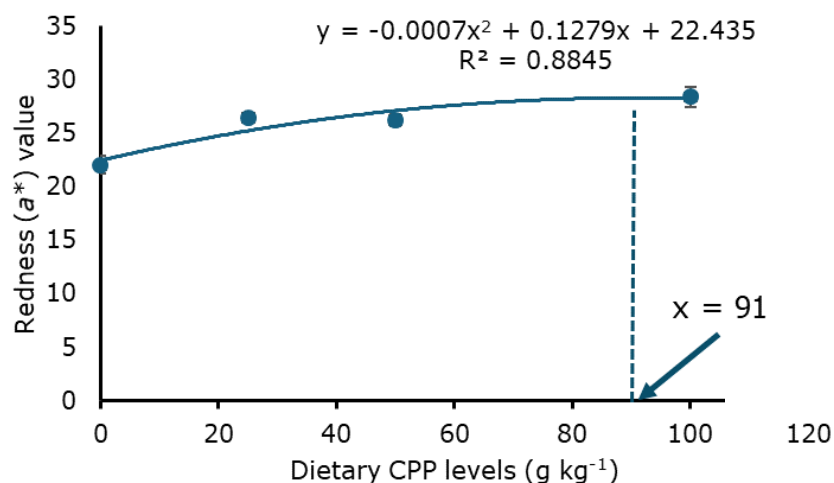


Figure 1. Polynomial regression analysis between a^* color coordinate and dietary CPP levels for goldfish.

Table 2

Growth performance, feed utilization, and survival rate of goldfish fed with different levels of cantaloupe processing by-product powder (CPP) for 52 days

<i>Ingredient (g kg⁻¹)</i>	<i>Experimental diet</i>				<i>p-value</i>
	<i>Control</i>	<i>CPP 25 g kg⁻¹</i>	<i>CPP 50 g kg⁻¹</i>	<i>CPP 100 g kg⁻¹</i>	
Survival (% cumulative)	100	93.33±5.77	93.33±5.77	93.33±5.77	0.859
Average initial body weight (g fish ⁻¹)	5.44±0.06	5.43±0.05	5.44±0.08	5.43±0.11	0.999
Average final body weight (g fish ⁻¹)	7.87±0.18 ^a	8.76±0.30 ^c	8.68±0.40 ^{bc}	8.10±0.33 ^{ab}	0.021
Specific growth rate, SGR (% day ⁻¹)	0.71±0.06 ^a	0.92±0.08 ^b	0.90±0.08 ^b	0.77±0.11 ^{ab}	0.040
Feed intake, FI (g fish ⁻¹)	3.43±0.39	3.55±0.16	3.92±0.17	3.42±0.10	0.090
Feed conversion ratio, FCR	1.42±0.27	1.07±0.06	1.22±0.12	1.30±0.16	0.169
Protein efficiency ratio, PER	1.78±0.31 ^a	2.31±0.14 ^b	2.04±0.20 ^{ab}	1.78±0.03 ^a	0.031

Values are given as mean ($n = 3$) ± standard deviation. Mean values in the same row with different letters are significantly different ($p < 0.05$).

Table 3

Skin color parameters of goldfish fed with different levels of cantaloupe processing by-product powder (CPP) for 52 days

<i>Ingredient (g kg⁻¹)</i>	<i>Experimental diet</i>				<i>p-value</i>
	<i>Control</i>	<i>CPP 25 g kg⁻¹</i>	<i>CPP 50 g kg⁻¹</i>	<i>CPP 100 g kg⁻¹</i>	
Lightness (L^*)	57.70±1.29	54.99±4.34	51.89±1.67	51.48±6.76	0.291
Redness (a^*)	21.98±0.83 ^a	26.40±0.26 ^b	26.17±0.58 ^b	28.36±0.94 ^c	0.000
Yellowness (b^*)	45.77±1.43 ^a	52.34±2.40 ^b	50.44±0.78 ^b	56.39±2.32 ^c	0.001

Values are given as mean ($n = 9$ fish per treatment) ± standard deviation. Mean values in the same row with different letters are significantly different ($p < 0.05$).

Skin mucosal lysozyme activity. The skin mucus lysozyme activity of goldfish fed different concentrations of CPP for 52 days is presented in Figure 3. Goldfish in all experimental treatments supplemented with various levels of CPP exhibited significantly elevated ($p < 0.05$) skin mucosal lysozyme activity compared to the control group.

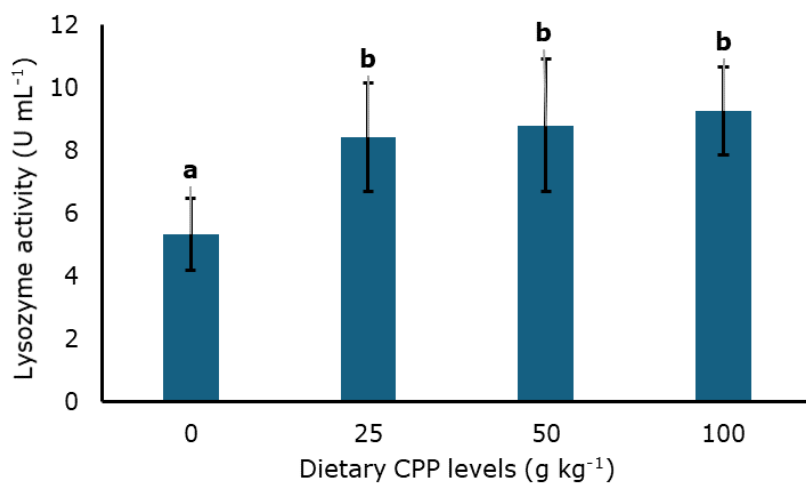


Figure 2. The skin mucosal lysozyme activity (unit mL⁻¹) of goldfish fed on dietary CPP levels for 52 days.

Discussion. The global market for ornamental fish and associated products is expected to grow, with an estimated trade value of USD 15-30 billion a year and a CAGR of 8.5% from 2023 to 2030 (Evers et al 2019; Hoseinifar et al 2023; Peh & Azra 2025). Feed is an important factor that enhances the growth, health status, and coloration of ornamental fish. Feed additives are employed in ornamental fish feed to enhance product quality to satisfy consumer demands. However, various commonly employed additives in ornamental fish feed are costly, leading to increased feed costs (Gouveia & Rema 2005; Dawood et al 2018). Recently, the variety of feed additives employed in aquaculture has continuously expanded with novel potential sources of feed additives, focusing on effectiveness, sustainability, and renewable sources. Several studies have demonstrated the beneficial effects of herbal and natural feed additives in promoting growth and coloration (Sathyaruban et al 2024; Chakroborty et al 2025). Fruit and vegetable waste, rich in bioactive compounds of interest, can effectively serve as an additive in ornamental fish feed. There are research reports on various fish species, including goldfish using date palm (*Phoenix dactylifera*) fruit (Heidarieh et al 2023); guppy (*Poecilia reticulata*) using palmyrah (*Borassus flabellifer* L.) fruit pulp (Sathyaruban et al 2024) or papaya (*Carica papaya*) peels (Rodrigo & Perera 2018); and fancy carp (*Cyprinus carpio*) using banana (*Musa acuminata*) peel (Sachintha et al 2020) or mulberry (*Morus alba*) fruit extract (Prisingkorn et al 2025).

The present study demonstrated that the inclusion of 25 or 50 g kg⁻¹ of CPP powder in goldfish diets enhanced growth performance. Similar results were also obtained by Vijayan et al (2024), who demonstrated that replacing 50% (125 g kg⁻¹ diet) of fishmeal with watermelon rind improved the growth performance and feed utilization of rohu (*Labeo rohita*) by enhancing nutrient digestibility and the health condition of the fish. Similarly, Van Doan et al (2020) demonstrated that incorporating 40 g kg⁻¹ of watermelon rind powder enhanced the growth performance of Nile tilapia. The observed findings can be associated with the presence of phenolic compounds, such as gallic acid and ferulic acid, in cantaloupe rinds, promoting fish growth and feed palatability and increasing feed intake of the diets (Mallek-Ayadi et al 2017). Furthermore, this promoting effect is combined with an increased secretion of major digestive enzymes, thereby ensuring improved digestion, absorption, and availability of essential nutrients (proteins, lipids, and carbohydrates) in fish (Koh et al 2016; Ghafarifarsani et al 2023). Moreover, the phenolic compounds could benefit the gut microbiota, resulting in improved anti-

inflammatory, antioxidant compounds and metabolic pathway function of essential amino acids, while preventing the proliferation of harmful microorganisms (Heidarieh et al 2023; Zhao et al 2024). However, the slightly decreased growth in fish fed the diet supplemented with 100 g kg⁻¹ of CPP powder may be related to the increased dietary fiber content with increasing levels of CPP supplementation in the diet, which decreased the retention time of digested nutrients in the gastrointestinal tract of fish, leading to inadequate nutrient digestion and absorption (Amirkolaie et al 2005; Vijayan et al 2024).

The pigmentation of ornamental fish significantly influences consumer demand, and it is due to an accumulation of carotenoids in the skin of the fish. Evidence indicates that fish lack the ability to synthesize all carotenoids (Goodwin 1984) and need to acquire these compounds through the diet. Astaxanthin is commonly used as an additive for enhancing the coloration of various ornamental fish. Nonetheless, astaxanthin is costly, and its improper use can negatively affect the health of fish and the ecosystem (de Souza Mesquita et al 2021; Tu et al 2022). Thus, the utilization of natural color enhancers has been an accepted approach in recent practices. Fruits and vegetables are rich in carotenoids and may be involved in several desirable biological processes (Saini et al 2015). The findings of this study demonstrate that the red color of goldfish supplemented with cantaloupe waste was elevated in comparison to those fed a control diet. This aligns with the findings of Pezeshk et al (2019), who indicated that the skin color of yellow cichlids increased when they were fed a diet that included cantaloupe waste. The pulp and rind of melons mostly consist of chlorophylls and carotenoids, with lutein and beta-carotene as the major carotenoids (Benmeziane et al 2018; Manchali et al 2021). Goldfish can convert lutein and beta-carotene from their diets into astaxanthin (Hsu et al 1972), providing a more intense red coloration. The findings support the efficiency of using cantaloupe waste for enhancing fish coloration.

Lysozyme is an important antimicrobial peptide in the innate immune system, serving to protect the host against pathogenic infections (Chen et al 2020). Lysozyme is widely present in the skin, mucus, gills, intestines, and serum of fish (Saurabh & Sahoo 2008). Research indicates that G-type lysozyme in the mucus of the Cyprinidae family of fish plays an important role in the immune response against several bacterial infections (Shabir et al 2024). The bactericidal activity of fish skin mucus is influenced by physiological and nutritional contents in the diet, particularly the immunostimulants administered to the fish (Subramanian et al 2008). The findings revealed that goldfish receiving diets supplemented with all formulations of CPP had increased lysozyme activity in their skin mucus compared to those on the control diet. Ghafarifarsani et al (2023) reported that gallic acid, found in cantaloupe waste, has potential as an immunostimulant that significantly improved serum immune responses, including lysozyme activity, ACH50, immunoglobulin (Ig), myeloperoxidase, and respiratory burst of common carp both before and after the crowding stress exposure. In addition, CPP is rich in lutein and β -carotene, which can be converted into vitamin A, which in its turn is crucial for stimulating several biological processes, including immunological responses (Li et al 2011). Moreover, β -carotene can suppress free radicals and singlet molecular oxygen (Terao et al 2010), thereby enhancing the immune system in fish. The results agree with Heidarieh et al (2023), who revealed improved mucosal immunity and liver antioxidant capacity in goldfish that were fed date palm fruit. Furthermore, Abdollahi et al (2019) reported that the mucosal lysozyme activity of the platyfish *Xiphophorus maculatus* showed elevated responses in the group that received β -carotene bioencapsulated in *Artemia franciscana*.

Conclusions. This study evaluated the effects of cantaloupe processing by-product on the growth performance, pigmentation, and mucosal lysozyme activity of goldfish. The results revealed that supplementation at 55 g kg⁻¹ of cantaloupe processing by-product maximized growth performance but did not have any adverse effects on feed utilization. In addition, the inclusion of 91 g kg⁻¹ of cantaloupe processing by-product would maximize skin coloration to the highest a^* color coordinate. Furthermore, our results suggest that supplementation with 25-100 g kg⁻¹ of cantaloupe processing by-product can enhance mucosal lysozyme activity. Therefore, it is recommended that cantaloupe by-

products be further tested and used as feed additives for goldfish diets in the ornamental fish industry, as well as in the aquaculture industry as natural raw materials that provide benefits for growth, health, and product quality.

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Conflict of interest. The authors declare that there is no conflict of interest.

References

- Abdollahi Y., Ahmadifard N., Agh N., Rahmanifarah K., Hejazi M. A., 2019 β -carotene-enriched *Artemia* as a natural carotenoid improved skin pigmentation and enhanced the mucus immune responses of platyfish *Xiphophorus maculatus*. *Aquaculture International* 27:1847-1858.
- Ahmad Z., Gao B., Mosa A., Yu H., Yin X., Bashir A., Ghoveisi H., Wang S., 2018 Removal of Cu (II), Cd (II) and Pb (II) ions from aqueous solutions by biochars derived from potassium-rich biomass. *Journal of Cleaner Production* 180:437-449.
- Amirkolaie A. K., Leenhouders J. I., Verreth J. A. J., Schrama J. W., 2005 Type of dietary fibre (soluble versus insoluble) influences digestion, faeces characteristics and faecal waste production in Nile tilapia (*Oreochromis niloticus* L.). *Aquaculture Research* 36(12):1157-1166.
- AOAC (Association of Official Analytical Chemists), 1995 Official methods of analysis of AOAC International. 16th edition. Association of Analytical Communities, Arlington, VA, 1899 pp.
- Azimirad M., Meshkini S., Ahmadifard N., Hoseinifar S. H., 2016 The effects of feeding with synbiotic (*Pediococcus acidilactici* and fructooligosaccharide) enriched adult *Artemia* on skin mucus immune responses, stress resistance, intestinal microbiota and performance of angelfish (*Pterophyllum scalare*). *Fish and Shellfish Immunology* 54:516-522.
- Baloglu M. C., 2018 Genomics of cucurbits. In: Genetic engineering of horticultural crops. Rout G. R., Peter K. V. (eds), Academic Press, London, pp. 413-432.
- Benmeziane A., Boulekbache-Makhlouf L., Mapelli-Brahm P., Khodja N. K., Remini H., Madani K., Meléndez-Martínez A. J., 2018 Extraction of carotenoids from cantaloupe waste and determination of its mineral composition. *Food Research International* 111:391-398.
- Chakroborty K., Lima R. A., Hossain M. F., Rafiquzzaman S. M., 2025 Biobased functional feed additives in Asian aquaculture: trends, impacts, and future directions. *Animal Feed Science and Technology* 320:116222.
- Chen T., Rao Y., Li J., Ren C., Tang D., Lin T., Ji J., Chen R., Yan A., 2020 Two distinct C-type lysozymes in goldfish: molecular characterization, antimicrobial potential, and transcriptional regulation in response to opposing effects of bacteria/lipopolysaccharide and dexamethasone/leptin. *International Journal of Molecular Sciences* 21(2):501.
- CIE (International Commission on Illumination), 1976 Official recommendations on uniform colour space, colour difference equations and metric colour terms. Suppl. No. 2 to CIE Publication No. 15, Colorimetry Commission International de l'Eclairage, Paris.
- Dawood M. A. O., Koshio S., Esteban M. Á., 2018 Beneficial roles of feed additives as immunostimulants in aquaculture: a review. *Reviews in Aquaculture* 10(4):950-974.
- de Souza Mesquita L. M., Martins M., Pisani L. P., Ventura S. P. M., de Rosso V. V., 2021 Insights on the use of alternative solvents and technologies to recover bio-based food pigments. *Comprehensive Reviews in Food Science and Food Safety* 20(1): 787-818.

- Ellis A. E., 1990 Lysozyme assay. In: Technique in fish immunology. Stolen J. S., Fletcher T. C., Anderson D. P., Roberson B. S., van Muiswinkel W. B. (eds), SOS Publications, Fair Haven, NJ, pp. 101-103.
- Evers H. G., Pinnegar J. K., Taylor M. I., 2019 Where are they all from? Sources and sustainability in the ornamental freshwater fish trade. *Journal of Fish Biology* 94(6): 909-916.
- FAO, 2023 World food and agriculture – statistical yearbook 2023. FAO, Rome, 367 pp.
- FAO, 2025 Global fruit production in 2023, by selected variety (in million metric tons) [Graph]. Available at: <https://www.statista.com/statistics/264001/worldwide-production-of-fruit-by-variety/>. Accessed: February, 2025.
- Faulisi M. V., Palmeri R., Restuccia C., 2024 Multifunctional application of food grade extracts from fruit processing industry wastes: a sustainable approach to food and health preservation. *Food Bioscience* 62:105204.
- Fundo J. F., Miller F. A., Garcia E., Santos J. R., Silva C. L. M., Brandão T. R. S., 2018 Physicochemical characteristics, bioactive compounds and antioxidant activity in juice, pulp, peel and seeds of cantaloupe melon. *Journal of Food Measurement and Characterization* 12:292-300.
- Ghafariarsani H., Hoseinifar S. H., Adhami B., Rohani M. F., Van Doan H., 2023 Dietary gallic acid influences serum enzymatic parameters and immunological responses in *Cyprinus carpio* exposed to crowding stress. *Aquaculture Reports* 30:101630.
- Gómez-García R., Vilas-Boas A. A., Machado M., Campos D. A., Aguilar C. N., Madureira A. R., Pintado M., 2022 Impact of simulated *in vitro* gastrointestinal digestion on bioactive compounds, bioactivity and cytotoxicity of melon (*Cucumis melo* L. *inodorus*) peel juice powder. *Food Bioscience* 47:101726.
- Goodwin T. W., 1984 The biochemistry of carotenoids. Vol. II. Animals. 1st edition. Chapman & Hall, London, 224 pp.
- Gouveia L., Rema P., 2005 Effect of microalgal biomass concentration and temperature on ornamental goldfish (*Carassius auratus*) skin pigmentation. *Aquaculture Nutrition* 11(1):19-23.
- Hamdaoui O., Saoudi F., Chiha M., 2010 Utilization of an agricultural waste material, melon (*Cucumis melo* L.) peel, as a sorbent for the removal of cadmium from aqueous phase. *Desalination and Water Treatment* 21(1-3):228-237.
- Heidarieh M., Gholamhosseini A., Sheikhzadeh N., Esteban M. A., 2023 Effects of γ -irradiated date (*Phoenix dactylifera*) fruit on growth, immunological and antioxidant parameters of goldfish (*Carassius auratus*). *Fishes* 8(5):251.
- Hoseinifar S. H., Maradonna F., Faheem M., Harikrishnan R., Devi G., Ringø E., Van Doan H., Ashouri G., Gioacchini G., Carnevali O., 2023 Sustainable ornamental fish aquaculture: the implication of microbial feed additives. *Animals* 13(10):1583.
- Hsu W. J., Rodriguez D. B., Chichester C. O., 1972 The biosynthesis of astaxanthin. VI. The conversion of [^{14}C] lutein and [^{14}C] β -carotene in goldfish. *International Journal of Biochemistry* 3(15):333-338.
- Kesh H., Kaushik P., 2021 Advances in melon (*Cucumis melo* L.) breeding: an update. *Scientia Horticulturae* 282:110045.
- Khan R., Anwar F., Ghazali F. M., Mahyudin N. A., 2024 Valorization of waste: innovative techniques for extracting bioactive compounds from fruit and vegetable peels - a comprehensive review. *Innovative Food Science and Emerging Technologies* 97: 103828.
- Koh C. B., Romano N., Zahrah A. S., Ng W. K., 2016 Effects of a dietary organic acids blend and oxytetracycline on the growth, nutrient utilization and total cultivable gut microbiota of the red hybrid tilapia, *Oreochromis* sp., and resistance to *Streptococcus agalactiae*. *Aquaculture Research* 47(2):357-369.
- Li M. H., Robinson E. H., Oberle D. F., Lucas P. M., Peterson B. C., Bates T. D., 2011 Clearance of yellow pigments lutein and zeaxanthin in channel catfish, *Ictalurus punctatus*, reared at different water temperatures. *Journal of the World Aquaculture Society* 42(1):105-110.

- Li Y., Chen Z., Peng Y., Zheng K., Ye C., Wan K., Zhang S., 2020 Changes in aerobic fermentation and microbial community structure in food waste derived from different dietary regimes. *Bioresource Technology* 317:123948.
- Mallek-Ayadi S., Bahloul N., Kechaou N., 2017 Characterization, phenolic compounds and functional properties of *Cucumis melo* L. peels. *Food Chemistry* 221:1691-1697.
- Manchali S., Chidambara Murthy K. N., Vishnuvardana, Patil B. S., 2021 Nutritional composition and health benefits of various botanical types of melon (*Cucumis melo* L.). *Plants* 10(9):1755.
- Peh J. H., Azra M. N., 2025 A global review of ornamental fish and shellfish research. *Aquaculture* 596(1):741719.
- Pezeshk F., Babaei S., Abedian Kenari A., Hedayati M., Naseri M., 2019 The effect of supplementing diets with extracts derived from three different species of macroalgae on growth, thermal stress resistance, antioxidant enzyme activities and skin colour of electric yellow cichlid (*Labidochromis caeruleus*). *Aquaculture Nutrition* 25(2):436-443.
- Prisingkorn W., Rinthong P., Kamolrat N., Wiriypattanasub P., Wongmaneeprateep S., Suriyaphan J., Pholoeng A., Wangkahart E., 2025 Impact of dietary mulberry (*Morus alba*) fruit extract on the growth performance, skin color, and immune response of fancy carp (*Cyprinus carpio*). *Aquaculture Reports* 40:102611.
- Rico X., Yáñez R., Gullón B., 2023 Evaluation of strategies for enhanced bioethanol production from melon peel waste. *Fuel* 334(2):126710.
- Rodrigo U. D., Perera B. G. K., 2018 Important biological activities of papaya peel extracts and their importance in formulation of a low-cost fish feed to enhance the skin colour and the healthiness of guppies. *International Journal of Scientific and Research Publications* 8(12):702-708.
- Rolim P. M., Seabra L. M. A. J., de Macedo G. R., 2020 Melon by-products: biopotential in human health and food processing. *Food Reviews International* 36(1):15-38.
- Sachintha S. L., Coswatte A. C. W. W. M. C. L. K., Bambaranda B. V. A. S. M., 2020 Development of fish feed using marigold petals and banana peel to enhance the coloration of koi carp (*Cyprinus carpio*). In: *Proceedings of the International Research Conference of Uva Wellassa University, Uva Wellassa University, Sri Lanka*, pp. 97-97.
- Saini R. K., Nile S. H., Park S. W., 2015 Carotenoids from fruits and vegetables: chemistry, analysis, occurrence, bioavailability and biological activities. *Food Research International* 76(3):735-750.
- Sathyaruban S., Perera G. S. C., Amarasinghe D. H. J. M., Uluwaduge D. I., Kuganathan S., 2024 Efficiency of the experimental diet enriched with palmyrah (*Borassus flabellifer* L.) fruit pulp on growth, pigmentation, immune challenge, and breeding performance in the guppy (*Poecilia reticulata*). *Aquaculture Reports* 38:102285.
- Saurabh S., Sahoo P. K., 2008 Lysozyme: an important defence molecule of fish innate immune system. *Aquaculture Research* 39(3):223-239.
- Scarano P., Sciarrillo R., Tartaglia M., Zuzolo D., Guarino C., 2022 Circular economy and secondary raw materials from fruits as sustainable source for recovery and reuse. A review. *Trends in Food Science and Technology* 122:157-170.
- Schaefer H., Renner S. S., 2011 Phylogenetic relationships in the order Cucurbitales and a new classification of the gourd family (Cucurbitaceae). *Taxon* 60(1):122-138.
- Shabir U., Dar J. S., Bhat A. H., Ganai B. A., Mahmoud M. H., Batiha G. E., 2024 Uncovering the antimicrobial activity of G-type lysozyme 2 derived from *Cyprinus carpio* mucus against bacterial and fungal pathogens. *Developmental and Comparative Immunology* 153:105135.
- Statista, 2025 Fresh fruits - worldwide. Available at: <https://www.statista.com/outlook/cmo/food/fruits-nuts/fresh-fruits/worldwide>. Accessed: April, 2025.
- Subramanian S., Ross N. W., MacKinnon S. L., 2008 Comparison of antimicrobial activity in the epidermal mucus extracts of fish. *Comparative Biochemistry and Physiology. Part B: Biochemistry and Molecular Biology* 150(1):85-92.

- Terao J., Minami Y., Bando N., 2010 Singlet molecular oxygen-quenching activity of carotenoids: relevance to protection of the skin from photoaging. *Journal of Clinical Biochemistry and Nutrition* 48(1):57-62.
- Tu N. P. C., Ha N. N., Linh N. T. T., Tri N. N., 2022 Effect of astaxanthin and spirulina levels in black soldier fly larvae meal-based diets on growth performance and skin pigmentation in discus fish, *Symphysodon* sp. *Aquaculture* 553:738048.
- United Nations, 2024 Progress towards the sustainable development goals. Report of the Secretary-General. A/79/79-E/2024/54, 26 pp.
- Van Doan H., Lumsangkul C., Hoseinifar S. H., Hung T. Q., Stejskal V., Ringø E., Dawood M. A. O., Esteban M. Á., 2020 Administration of watermelon rind powder to Nile tilapia (*Oreochromis niloticus*) culture under biofloc system: effect on growth performance, innate immune response, and disease resistance. *Aquaculture* 528:735574.
- Vijayan L., Arumugam M., Palaniyappan S., Jayaraman S., Brown P. B., Kari Z. A., Abdel-Warith A. W. A., Younis E. M., Ramasamy T., 2024 Utilization of sustainable agri-waste watermelon rind for fishmeal in *Labeo rohita* diets: effects on nutritional indices, hemato-biochemical properties, histoarchitectural traits, amino acid and fatty acid profiles. *Aquaculture Reports* 36:102045.
- Wanapat M., Suriyapha C., Dagaew G., Prachumchai R., Phupaboon S., Sommai S., Matra M., 2024 The recycling of tropical fruit peel waste-products applied in feed additive for ruminants: food manufacturing industries, phytonutrient properties, mechanisms, and future applications. *Journal of Agriculture and Food Research* 17:101234.
- Zhao X., Zhang L., Wu N., Liu Y., Xie J., Su L., Zhu Q., Unger B. H., Altaf F., Hu Y., Ye W., Qiao Z., Cheng Y., Zhang W., Wang Y., Xia X. Q., 2024 Gallic acid acts as an anti-inflammatory agent via PPAR γ -mediated immunomodulation and antioxidation in fish gut-liver axis. *Aquaculture* 578:740142.

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Authors:

Panisara Wongrak, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: Panisara.2402@gmail.com

Petlada Petchu, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: petladapetchom@gmail.com

Kanlayanee Assana, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: kanlayanee.2546@gmail.com

Nanthavich Suanyamo, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: Nanthwichys@gmail.com

Tanaphat Rakwong, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: Tanaphat2946@gmail.com

Patiwat Rodtongsan, Kidchakan Supamattaya Aquatic Animal Health Research Center, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: patiwat00ko00@gmail.com

Niracha Ratdee, Kidchakan Supamattaya Aquatic Animal Health Research Center, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: niracha.4761@gmail.com

Dame Korn, Kidchakan Supamattaya Aquatic Animal Health Research Center, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: damelove860@gmail.com

Akkarawit Issaro, Kidchakan Supamattaya Aquatic Animal Health Research Center, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: akkarawit.i@psu.ac.th

Nutt Nuntapong, Kidchakan Supamattaya Aquatic Animal Health Research Center, Aquatic Science and Innovative Management Division, Faculty of Natural Resources, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand, e-mail: nutt.n@psu.ac.th

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