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REVIEW ARTICLE

The influence of insect-derived and marine-based diets on sensory quality of poultry meat and egg: a systematic review

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Abstract The poultry industry is trying to reduce feed costs by replacing soybeans and corn with new protein sources like insect-derived (ID) and marine-based (MB) ingredients. This strategy requires evaluating not only chicken performance and carcass characteristics, but also the sensory properties of the produced meat and eggs. The MB and ID products are potentially valuable sources of proteins, amino acids, fatty acids, vitamins and minerals in animal nutrition. This systematic review reports the effects of using these ingredients including fishmeal and oil, fish protein hydrolysates, fish silage, and seaweeds and insect products like insects' protein and oil on the sensory properties of poultry meat and eggs. Studies show that excessive use of these compounds in poultry diet has a significant effect on the sensory properties of meat and eggs. However, there are conflicting reports regarding the use of ID and MD ingredients and their effects on the sensory properties of poultry meat and eggs. Therefore, it is necessary to have a systematic literature review on the subject and draw a clear conclusion. The study emphasizes the importance of using sensory assessment in the poultry nutrition studies' when using new ingredients and providing practical information for poultry nutritionists and processing professionals.

Keywords Poultry · Insect-derived diet · Marine-based feed · Seaweed · Sensory evaluation

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Abbreviations

BSF	Black soldier fly
FPH	Fish protein hydrolysate
EW	Earth worm
GH	Grasshopper
ID	Insect-derived
HF	Housefly
MB	Marine-based
MW	Mealworm
QDA	Quantitative descriptive analysis
SWP	Silk worm pupae

Introduction

Poultry farming is one of the most important agricultural sub-sectors in many countries, which is supported by the governments and the private sectors with the aim of providing the meat and eggs for consumers (Michalak and Mahrose 2020). Reducing feed costs is a major concern for poultry meat and egg producers. Therefore, the need to find sustainable alternatives for poultry feeding is very important (Etemadian et al. 2021). In recent years, increasing interest in using insect-derived (ID) and marine-based (MB) feeds for animal nutrition has led to increase research studies in this field. On the other hand, the world population will exceed 9 billion people by the year 2050. Accordingly, food security and environmental problems will be among the most significant issues of that time. Therefore, in the near future, the demand for this type of animal feeds will increase significantly (Khan et al. 2018). The ID and MB ingredients are rich in valuable proteins, amino acids, fatty acids and energy, vitamins and minerals. Therefore, they will be suitable resources for animal nutrition. Replacing corn and soybeans with these compounds in poultry diet requires not only the evaluation of poultry performance and carcass characteristics, but also the sensory quality of the produced meat and eggs (Shaviklo et al. 2021a, b).

Although nutritional value is very important in the acceptance of a foodstuff, but its sensory quality is a priority for continuous buying and consumption of the product (Meilgaard et al. 2015). The sensory properties of feedstuffs affect the sensory quality of animal products such as meat and eggs, and in this context, it is necessary to know sensory attributes of feed ingredients. Providing such data are required before the introduction of food products to the market or when using new ingredients in livestock farming (Shaviklo et al. 2021a, b). The odor and flavor of fish and seaweed, bitterness, rancidity etc. are the sensory characteristics of the MB products that are used as animal feed. The ID ingredients have unique sensory attributes like chickpeas odor and flavor in mealworm powder (Shaviklo et al. 2021a).

The sensory characteristics of poultry meat and eggs are influenced by various factors including the genetics of birds, the farming system, the animal diet and the age of birds at slaughter (Al-Marzooqi et al. 2010). It is obvious that the use of the ID and MB products in poultry feed may cause significant changes in the approximate analysis and composition of meat fatty acids (Gasco et al. 2016) and sensory attributes of the poultry products (Shaviklo et al., 2021a,b).

To date, most of the published studies on using ID and MB ingredients in feeding poultries have focused mainly on growth performance, safety, and feed composition and utilization. However, sensory evaluation in considerable published studies has not been performed carefully. Therefore, the main purpose of this study is to provide a systematic review of research, using the following methodology, on ID and MB ingredients as they affect sensory attributes of poultry meat and eggs at different levels of inclusion. This study also tries to emphasize the importance of applying standard-based sensory evaluation in animal, including poultry nutrition studies when formulating new feed materials.

Research design and methodology

A systematic literature review that is based on synthesis methodology and described by Heyn et al. (2019) was carried out. Accordingly, the adapted methodology consisted following five important and distinct phases:

Study objective—There are conflicting reports regarding the use of ID & MD ingredients and their effects on the sensory properties of poultry meat and eggs. Therefore, the objective of this study was to compile and review literature on the subject and draw a clear conclusion from studies.

Literature search—Google Scholar database was searched for all available and updated literature from 1960–2022 on the use of ID & MD feed products for poultry farming and their influences on the sensory quality of meat and eggs. The relevant articles were compiled.

Data screening—Compiled articles were screened and only articles whose research methods of sensory evaluation were in line with standard methods were selected for reviewing.

Review—Each study was reviewed for synthesis. The research methods and outcomes of the studies were extracted. Accordingly, they were critically evaluated with complete impartiality.

Presenting the results: Factors affecting sensory quality of food products were defined. The ID and MD ingredients and their application in poultry diet were introduced. The sensory attributes of poultry meat and eggs fed with these compounds were discussed. Two summary tables were well-organized, to report the inclusion levels, avian species, farming period, sensory method, sample preparation and the sensory results which will help the readers to understand the topic clearly.

Factors affecting sensory evaluation results

Panelists' selection and their training

The most important tool in product development and food quality control is establishment of an efficient sensory evaluation team. The objective of a study defines how to select and train the panelists, and this affects success or failure of the sensory assessment. The training of assessors and their experience is very effective in the ability to understand sensory differences or similarities. Therefore, if a similar sample is presented for sensory evaluation between two groups of trained and untrained assessments, having different results is not unexpected (Meilgaard et al. 2015). International Organization for Standardization (ISO) has issued relevant standards for sensory evaluation. ISO (8589: 2007) presents general guidance for the design of test rooms (ISO 2007) and ISO (8596:2012) describes general guidelines on how to select, train and monitor assessor's performance which is recommended to be applied for food sensory analysis (ISO, 8596:2012).

Sensory evaluation methods

Sensory testing can be classified into two areas: analytical or objective and affective or subjective. Analytical testing is applied in the laboratory to reveal similarities or differences between the products by a selected and trained panel. Descriptive and discrimination tests are the most important analytical tests. In affective testing, the consumer's reactions to sensory attributes of products are assessed using preference or acceptance tests (Meilgaard et al. 2015).

To distinguish differences or similarities of two products, differences or discrimination tests are used. Discrimination experiments generally use large numbers of participants to estimate the proportion of the population that can distinguish between the two products (Stone et al. 2020).

The triangle test is the most widely used test of sensory differentiation. Thresholds in sensory testing are usually expressed as the minimum detectable level of concentration of a substance. These tests are used for training of assessors. Descriptive tests or sensory profiling techniques are applied to determine sensory attributes and their severities. The most widely used descriptive techniques are Quantitative descriptive analysis (QDA) (Meilgaard et al. 2015; Stone et al. 2020). A successful descriptive analysis depends on 3 factors: training and experience of the assessors, designing and conducting the sensory test, and the role of panel leader in establishment and maintenance of a sensory panel (Meilgaard et al. 2015).

Sensory vocabulary

A sensory vocabulary is a list of standard lexicon prepared by a sensory team to determine the sensory attributes of a product, and it is used in the training of the assessors and for sample evaluation, too. The preparation of the vocabulary is one of the basic steps in descriptive sensory analysis (Meilgaard et al. 2015). To create a vocabulary, sensory assessors evaluate samples that, as far as possible, represent the entire product. They define terms to describe each sensory property of the samples and provide references for better comparison and understanding of the sensory properties. The terms mentioned in the vocabulary should be simple, broad, and complete, and include all product differences. In most cases, assessors also assign a score to each reference standard to determine the intensity of each sensory attribute (Stone et al. 2020). It is as an effective communication tool among different audiences such as assessors, sensory experts, food producers, marketing professionals, and suppliers who may have different perceptions of the correct sensory feature due to differences in perception, knowledge and background (Meilgaard et al. 2015; Stone et al. 2020). Shaviklo et al. (2021b) developed a vocabulary consisting of 17 terms for describing the influence of fish protein hydrolysate-based supplement on the odor, taste and flavor, and texture properties of cooked chicken breast fillets (Table 1). A lexicon for sensory evaluation of chicken eggs prepared by Feng et al. (2020) is presented in Table 2.

The ID products

A high quality protein source for human and animal's nutrition is insect (Khan et al. 2018). For example, the protein, fat and mineral contents of mealworm larvae was noted 52, 24 and 1% in dry sample, respectively (Zielińska et al.

Table 1 Vocabulary prepared by Shaviklo et al. (2021b) used for sensory evaluation of cooked chicken breast

Sensory attribute	Scale (0–100)	Definitions
Odor		
Chicken	None | much	How strong is the aroma of fresh chicken meat?
Fish	None | much	How strong is the aroma of fresh fish meat?
Off-odor	None | much	How strong is the off-odor?
Metallic	None | much	How strong is the aroma of iron?
Flavor/ Taste		
Chicken	None | much	How strong is the flavor of fresh chicken meat?
Fish	None | much	How strong is the flavor of fresh fish meat?
Off-odor	None | much	How strong is the off-flavor?
Metallic	None | much	How strong is the flavor of iron?
Umami	None | much	How strong is the of umami taste?
Sweet	None | much	How strong is the of umami taste?
Salty	None | much	How strong is the of umami taste?
Bitter	None | much	How strong is the bitterness taste?
Astringency	None | much	How strong is the astringency?
*Texture**		
Tenderness	Firm | soft	How tender is the sample up to the fourth chewing?
Elasticity	Little | much	How 'elastic-like' is the sample up to the fourth chewing?
Juiciness	Dry | juicy	How juicy is the sample up to the fourth chewing?
Acceptance		
Liking	None | much	How do you like it?

*Texture attributes were evaluated for cooked chicken fillet

Table 2 Sensory lexicon defined by Feng et al. (2020) for sensory analysis of chicken eggs

Attributes	Definition
Odor	
Egg	Odor associated with egg yolk
Fishy	Odor associated with fish
Barny	Odor associated with straw
Seaweed	Odor associated with seaweed
Flavor	
Egg	Flavor associated with egg yolk
Fishy	Flavor associated with fish fillet
Milky	Flavor associated with milk
Sweet	Flavor associated with sucrose
Buttery	Flavor associated with unsalted butter
Salty	Flavor associated with salt solution
Chicken	Flavor associated with chicken soup
Rancid	Flavor associated with citric acid

2015). Zhao et al. (2016) reported that mealworm larvae contained about 32% fat, 5% ash and 51% protein, on a dry weight basis for yellow mealworm (*Tenebrio molitor*) larvae. They announced that this insect has a good amino acid composition.

Different forms of the ID products are used for animal feeding (Fig. 1). The whole insect powder, insect protein powder and insect oil are frequently used in the animal farming. Insects can be used as a substitute for soybean meal and fishmeal in livestock and poultry feed due to having 30–40% fat and 40–60% protein in dry basis (Khan et al. 2018). Changes in animal feed protein sources from soybean meal and fishmeal to insects lead to more efficient use of natural sources and lead to less greenhouse gas emissions. For these reasons, many researchers have tried to apply insect protein in poultry nutrition. Chickens raised in the wild collect and eat insects at all stages of life indicating that they are evolutionary adapted to feeding insects as a natural part of their nutrition. Therefore, application of insect proteins in the production of livestock and poultry feed and the development of insect breeding systems seems reasonable (Khan et al. 2018). The most important insects used for poultry feeding are: mealworm (MW), housefly (HF), black soldier fly (BSF), earth worm (EW), grasshopper (GH), silk worm pupae (SWP), *Cirina forda* (westwood), cricket and locust (Khan et al. 2018).

Broilers are single-stomach animals and any changes in the chemical composition of their feed can affect the sensory characteristics of their meat positively or negatively (Pieterse et al. 2019). In the use of insects in poultry feed, reports

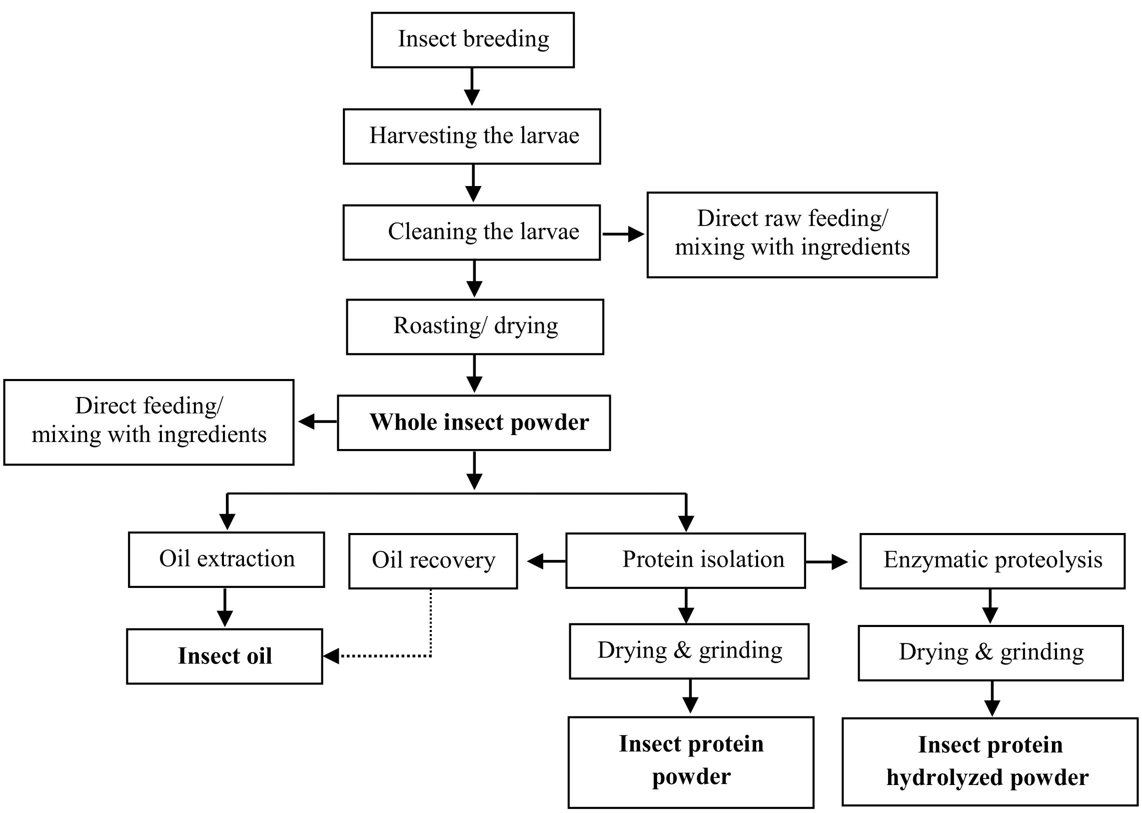


Fig. 1 Different forms of insects used as feed in animal nutrition

indicate that this ingredient improved the growth and performance of fed chickens. However, the sensory characteristics of insect-fed poultry meat or egg have not been carefully studied (Khan 2018).

In the last 60 years, little published document is available on the influence of feeding insects on the sensory quality of poultry meat. Some authors (Tables 3 and 4) provided important information on how to perform a sensory test, prepare and cook samples and design a liking scale. However, some other articles do not provide specific information about sensory methodology, sample preparation and assessors' selection and training. They did not publish information about vocabulary designing to define sensory characteristics, how to set up the questionnaire, and whether the test was blind or not.

Khan et al. (2018) conducted a study comparing the sensory characteristics of fed broiler chicken with different types of insect meal (e.g. mug meal, silkworm meal and mealworm) and concluded that the insect incorporated diet did not change sensory attributes ($p > 0.05$). Hwangbo et al. (2009) reported that the sensory attributes of chicken meat fed insect meal were not influenced ($p > 0.05$). Onsongo et al. (2018) also noted that incorporation of black soldier fly (*H. illucens*) meal in broiler feeding does not influence consumer preference for broiler breast meat consumption because the insect meals application did not alter the odor and flavor of meat ($p > 0.05$). These results are in line of Pieterse et al. (2019) study. However, chicken breast fillet fed with black soldier fly (*H. illucens*) had the strongest flavor ($p < 0.05$) among the treatments (Altmann et al. 2018). The larvae fed meat treatments scored significantly higher ($p < 0.05$) for juiciness compared to the fishmeal fed treatments. This study also indicated that broilers received larvae meal could have juicier meat (Pieterse et al. 2014).

Feng et al. (1985) studied differences between the meat of broilers fed the corn-ground cricket and corn-soybean meal diet using a triangle test with 26 panelists. No significant difference in the taste of two samples were reported ($p > 0.05$). Studies carried out on broilers fed several levels of black soldier fly (*H. illucens*) mealworm (*Tenebrio molitor*) indicated that there were no significant differences for the chicken meat color (Secci et al. 2018; Pieterse et al. 2019). However, other work (Pieterse et al. 2014) reported that application of black soldier fly (*H. illucens*) and housefly (*Musca domestica*) larvae influenced the broilers and quail's meat color significantly ($p < 0.05$).

Application of insects in broiler quails and chickens diet did not influence ($p > 0.05$) sensory properties of the meat (Onsongo et al. 2018; Pieterse et al. 2019). Altmann et al. (2018) instead stated that black soldier fly (*H. illucens*) fed broiler breast had a strong taste that reduced within storage time ($p < 0.05$). A higher metallic odor and aftertaste values was reported by Pieterse et al. (2019) for broilers meat fed black soldier fly larvae ($p < 0.05$). The meat was juicier than chickens fed soybean flour and fish based diet. Khan et al. (2018) revealed that different level of maggot meal, silkworm meal and mealworm did not influence the chicken meat flavor ($p < 0.05$), but the chickens fed mealworm scored higher tenderness and juiciness values when compared to the other treatments ($p < 0.05$).

The influence of grasshoppers incorporated feed on sensory properties of chickens farmed in free-range and grassland-based systems were studied (Sun et al. 2013). The results indicated that all breast and thigh meats treatments had the same color and juiciness ($p > 0.05$), but significant higher scores ($p < 0.05$) for odor and flavor, chewiness and acceptance and lower scores for tenderness were observed for the chickens fed with grasshoppers compared to the control samples which received a maize-soybean feed.

Bovera et al. (2016) studied incorporation of black soldier fly meal at 29.65% level in broilers chicken diet feeding for 32 days. No significant influence on ($p < 0.05$) the broiler meat color was reported. Onsongo et al. (2018) reported that inclusion 5–15% black solder fly meal in broilers meat had no effect on odor and flavor ($p > 0.05$). Altmann (2018) reported the same results. Khan et al. (2018) studied inclusion of 7.8% silkworm (*Bombyx mori*), 8% housefly (*Musca domestica*) and 8.1% mealworm (*Tenebrio molitor*) larvae meal in broiler chicken diet for 35 days and reported that tenderness and juiciness of meat were significantly higher in mealworm group compared to the control and other treatments ($p < 0.05$).

Egg breed, breeding systems, and diets supplementation are factors influencing sensory attributes of egg (Zeweil et al. 2019). Al-Qazzaz et al. (2016) noted that an increase in black soldier fly application in laying hens, improved the shape and sensory attributes of obtained eggs compared to the control samples ($p < 0.05$). Incorporating more than 7.5%, fat free black soldier fly larvae in the corn-soybean diet for broilers from 19–27 weeks of age could increase egg yolk color intensity and eggshell thickness significantly ($p < 0.05$) as revealed by Mwaniki et al. (2018). However, a significant decrease ($p < 0.05$) in egg yolk color intensity of the free-range laying hens received black soldier fly larvae meal was noted (Ruhnke et al. 2018).

Secci et al. (2018) studied the influence of incorporating 17% black soldier fly larvae meal on laying hens fed 147 days and reported that it was contributed with the redder yolks ($p < 0.05$). It was in agreement with the work of Mwaniki et al. (2018) who applied 5 and 7.5% black soldier fly larvae meal in 182 days feeding in laying hen. Ruhnke et al. (2018) used 15% black soldier fly larvae meal in free-range laying hen for 12 weeks and reported that it decreased yolk color significantly ($p < 0.05$).

Dalle Zotte et al. (2019) incorporated 10 and 15% defatted black soldier fly larvae meal in laying quails for 6 weeks

Table 3 Summary of researches carried out in the recent years reporting the influence of MB and ID ingredients on sensory attributes of poultry meat

No	Type of ingredient	Methods and Results
MB ingredients		
1	Fishmeal *Ref* Dean et al. 1969	Inclusion levels: 3–19% Avian Species: Broiler chicken Farming period: 63 days Feeding days: 21 days from 42–63 days Sensory method: Triangle tests Number of assessors: 11 untrained panelists Test sample: Chicken skin and breast Sample preparation: Frozen broilers were defrosted overnight to a room temperature of about 2 l°C. The wrapped carcass in aluminum foil, were placed in an electric oven at 163 °C for 75 min. From each cooked carcass a 3 cm^2 skin and a 3 cm^3 breast meat and of thigh meat were selected Results: The flavor change was observed between birds fed 3 and 9% fishmeal with a significant difference that was found in skin and breast meat. However, in thigh meat had no effect on flavor until the level of fishmeal increased to 14%
2	Concentrated defatted farmed salmon silage *Ref* Kjos et al. 2000	Inclusion levels: 5% and 10% fish silage about 10 and 21% of total protein in diets Avian Species: Commercial Norwegian hybrid Farming period: 36 days Feeding days: 36 days from 1 to day 36 of age Sensory method: A 9-point hedonic scale was used for sensory analysis of vacuum-packed frozen tight meat within 1 month and 6 months of frozen storage at -16 °C Number of assessors: 10 trained panelists Test sample: Chicken meat Sample preparation: Meat samples were packed in the plastic bags and heated by immerging the bags in the hot water (80 °C) for 45 min Results: An inclusion level of up to 10% diet, corresponding to 21% of the total protein, had no significant effect on meat sensory attributes
3	Pollock fish oil *Ref* Huang et al. 2006	Inclusion levels: 0,1.5, and 3.0% Pollock fish oil Avian Species: Mule ducks (Muscovy ♂ × Kaiya ♀; Kaiya is the progeny of Pekin ♂ × white Tsaiya duck ♀) at 4 weeks of age Farming period: 10 weeks Feeding days: 6 weeks Sensory method: A 9-point hedonic scale was used for sensory analysis of breast meat Number of assessors: 12 panelists Test sample: Mule ducks' breast Sample preparation: Breast meat, was heated in an automatic smokehouse until its internal temperature reached 75 °C, and then cut into a slice of 0.4 cm Results: inclusion 1.5% fish oil in the diet did not affect sensory attributes of chicken meat significantly

Table 3 (continued)

No	Type of ingredient	Methods and Results
4	Co-dried Indian oil sardine's silage and crushed corn (85:15%) (CSS) *Ref* Al-Marzooqi et al. 2010	Inclusion levels: 0, 10, 20 and 30%, substituting for soybean meal Avian Species: Cobb 500 Farming period: 35 days Feeding days: 35 days from 0 to day 35 of age Sensory method: A five-point hedonic scale from 1 to 5 (1: the lowest intensity; 9: the highest intensity) was carried out Number of assessors: 30 panelists Test sample: Chicken breast Sample preparation: Chicken breast was traditionally cooked in pressure pots with no spices or additives Results: The panelists detected a fishy off-flavor in meat of birds fed 30% co-dried fish silage with corn. The co-dried fish silage with corn can replace up to 20% of soybean meal in broiler diets without affecting sensory quality of broiler meat
5	Co-dried biological fish silage and soybean meal (1:1 w/w) *Ref* Ramírez et al. 2013	Inclusion levels: 0, 10, 20 and 30% Avian Species: Quails (*Coturnix coturnix japonica*) Farming period: 35 days Feeding days: 35 days Sensory method: A 9- point hedonic scale was implemented Number of assessors: 14 panelists Test sample: Quail's breast Sample preparation: The frozen carcass stored 1 month at -20 °C, was defrosted in a microwave oven. The carcass was put in plastic bags, and heated in hot water (80 °C/45 min). Cooked breast meat was evaluated Results: Incorporation of co-dried fish silage and soybean meal up to 30% in the quail diet did not affect the quail meat sensory attributes
6	Spirulina (*Arthrospira platensis*) and de-fatted black soldier fly (*Hermetia illucens*) larval meal and *Ref* Altmann et al. 2020	Inclusion levels: 75% (starter diets) and 50% (grower diets) of the soymeal was substituted by either spirulina meal or black soldier fly meal Avian species: Ross-308 Farming period: 35 days Feeding days: 35 days Sensory method: Descriptive sensory profiling with a 10 cm unmarked line scale was applied Number of assessors: 12 trained assessors Test sample: Chicken breast Sample preparation: The samples were cooked *sous vide* at 77 °C for 60 min in a hot water bath to reach a core temperature of approximately 75 °C. Samples were cooled to room temperature outside the vacuum bag, and were cut into approximately 1cm^2 cubes Results: Diet affected the sensory attributes of chicken breast meat. Chicken breast produced with spirulina scored higher umami and chicken flavor. It also had a reduced off-odor (barn odor). In addition, chicken breast produced with black soldier fly was less adhesive during chewing and umami taste. Inclusion of spirulina and black soldier fly meal resulted in more yellow meat. Spirulina resulted redder meat

Table 3 (continued)

No	Type of ingredient	Methods and Results
7	Fish protein hydrolysate-based supplement (FPHS) *Ref* Shaviklo et al. 2021b	Inclusion levels: 2.5, 5.0 and 7.5% Avian Species: Ross 308 Farming period: 42 days Feeding days: 42 days Sensory method: Quantitative Descriptive Analysis (QDA) was used Number of assessors: 5 expert panel Test sample: Chicken breast and broth Sample preparation: 1) chicken broth was prepared by boiling a piece of chicken breast. 2) the bone-less and skinless fillet samples were grilled in a commercial oven for 40 min at 190 ± 5 ˚C until they reached a core temperature of 75 ˚C Results: No significant differences were found for chicken odor and flavor, within the chicken broth of the treatments. Umami taste and liking in the chicken broth was only detected in the birds fed with FPHS and these treatments were more liked comparing to the control. Attributes like odor and flavor, metallic odor and flavor, off-odor/ flavor, and bitterness were not detected in the treatments fed FPHS
ID ingredient		
8	Phane worm (*Imbrasia belina*) meal (PWM) *Ref* Mareko et al. 2010	Inclusion levels: 0%, 20%, 40% Avian species: Cobb 500 Farming period: 46 days Feeding days: 28 days from 18–46 days Sensory method: A 5-point hedonic scale was used Number of assessors: 24 trained panelists Test sample: Chicken breast Sample preparation: Drumsticks were defrosted overnight at 15 °C and cooked in the conventional boiling condition for 30 min. The portions were then cut into cubs (1 × 5 cm) and given to the assessors Results: No significant difference was observed among treatments regarding odor, flavor, juiciness and acceptance
9	Live grasshoppers (*Disambiguation*) *Ref* Sun et al. 2013	Inclusion levels: Rearing broilers on rangelands Avian Species: Broiler chicken of the strain Qinjiaoma Farming period: 91 days Feeding days: 63 days Sensory method: A 5-point hedonic scale was carried out Number of assessors: 10 trained panelists Test sample: Chicken breast Sample preparation: Packed and frozen left skinless breast and thighs stored 2 months at -20 were defrosted for 24 h in a refrigerator with 4–8 °C temperature. Samples were heated in a pre-warmed 200 °C oven to a final temperature of 75 °C. Thigh cooking needed 20 min more than the breast. Cooked samples were then cut into 2 or 3 cubes of 2 cm. Two pieces of each portion were presented to the assessors Results: The panelists did not detect any significance differences in color and juiciness of the breast or thigh meats between samples

Table 3 (continued)

No	Type of ingredient	Methods and Results
10	Silkworm (*Bombyx mori*) pupa *Ref* Mentang et al. 2013	Inclusion levels: 1) basal diet containing 10% fish meal (control), 2,3) basal diet containing 10 and 20% dried silkworm, 4) basal diet containing 5% dried silkworm + 5% fresh silkworm, 5) basal diet containing 10% dried silkworm + 10% fresh silkworm Avian Species: 3 weeks old male commercial broilers (CPC 707) Farming period: 21 days Feeding days: 21 days Sensory method: A 9- point anchored hedonic scale was carried out Number of assessors: 18 trained panelists Test sample: Chicken breast Sample preparation: Chicken meat was cut to the size of 1.5 × 1.5 × 4 cm and steamed at 100 ˚C to achieve an internal temperature of 75 ˚C. Then samples were presented to the panelists Results: No significant differences were found among the treatments for sensory attributes of cooked breast meat
MB ingredients		
11	*Musca domestica* larvae meal *Ref* Pieterse et al. 2014	Inclusion levels: 0% larvae or fish meal (soya bean as protein source; control) and 10% larvae or 10% fish meal, Avian Species: Day-old Ross 308 broiler chicks Farming period: 32 days Feeding days: 32 days Sensory method: Quantitative Descriptive Analysis (QDA) was carried out Number of assessors: 9 trained panelists Test sample: Chicken breast Sample preparation: The vacuum packed and frozen right side, skinless breast meats were defrosted in a refrigerator at 4 °C for 24 h. The breast meat was packed in roasting bags. They were put on a preheated oven at 160 °C, and cooked to reach an internal temperature of 75 °C. The cooked meat was removed from the roasting bags and cut into cubes of about1.5 × 1.5 × 1.5 cm. The meat cubes were wrapped individually in aluminium foil and placed into numbered heat proof cups. Two meat cubes were presented to each assessor after reheating samples at 100 °C for 10 min in convection ovens Results: No differences were reported for chicken odor, initial juiciness, chicken flavor or hardness. Significant differences were observed for metallic odor and metallic aftertaste in the treatments. The higher scores were reported for larvae-fed chickens compared to the fishmeal-fed and control chickens' treatments. However, the mean values were very low and the consumer is unlikely to find the differences
12	Black soldier fly (*Hemetia illucens*) Larva fat (BSFF) *Ref* Cullere et al. 2019	Inclusion levels: 50 or 100% replacement of soybean oil with BSFF Avian Species: Ross 708 Farming period: 38 days Feeding days: 27 days from 21–48 days of age Sensory method: A descriptive sensory analysis with a 10- point anchored hedonic scale was carried out Number of assessors: 8 trained panelists Test sample: Chicken breast Sample preparation: Left side of the frozen breasts stored at 40 ˚C for 1 month were defrosted for 4 h at 4 ˚C Results: Inclusion of BSFF did not affect sensory attributes of breast meat in all treatments including control

Table 3 (continued)

No	Type of ingredient	Methods and Results
13	Dehydrated larvae of housefly (*Musca domestica*) (DLH) *Ref* Radulović et al. 2018	Inclusion levels: 5% (% as fed basis) of the starter diet and 4% of the grower and finisher diets Avian species: Cobb 500 Farming period: 42 days Feeding days: 42 days Sensory method: A 5-point hedonic scale was used Number of assessors: 10 trained panelists Test sample: Chicken meat Sample preparation: Breasts and legs with thighs samples were heated treatment in an electric oven, at 170˚C, until it reaches a constant internal temperature of 80˚C. The cooked meat samples were cut to approximately 2.5 × 2.5 × 2.5 cm pieces for evaluation Results: No significant difference was observed for tenderness and juiciness among samples. The diet had significant impact on the odor and flavor of the breasts and legs with thighs respectively. However, the highest acceptance score was given to the chickens fed DLH
14	Earth worm (*Eisenia foetida*) meal (EWM) *Ref* Gunya et al. 2019	Inclusion levels: Substituting fishmeal at 1, 3, 5 and 10% Avian Species: Cobb Farming period: 35 days Feeding days: 35 days Sensory method: A 5- point anchored hedonic scale was used Number of assessors: 10 untrained panelists Test sample: Chicken breast Sample preparation: Frozen breast samples were defrosted in a refrigerator at 4 ˚C for 12 h. Each sample was cut into 10 mm thick strips, vacuum packed and boiled for 50 min at 85 ˚C without any salt or spice Results: Inclusion of EWM affected and improved sensory attributes of breast meat
15	Mopane worm (*Gonimbrasia belina*) (MoW) *Ref* Manyeula et al. 2019	Inclusion levels: 2.4, 4.8% Avian Species: 25 weeks old Tswana hens Farming period: 13 weeks Feeding days: 13 weeks from 25–38 weeks Sensory method: A 5- point hedonic scale was used Number of assessors: 30 untrained panelists Test sample: Chicken breast Sample preparation: Chicken breast, thighs and drumsticks were cut and boiled for 1 h a day after slaughtering. The meat samples were cut into pieces of about 2 × 5 cm pieces for evaluation Results: Inclusion MoW in the layer hen diets as protein sources did not affect sensory attributes of chicken meat
16	Edible grasshopper (*disambiguation*) meal (EGM) *Ref* Nginya et al. 2019	Inclusion levels: 0, 25, 50, 75 and 100% Avian Species: 4 weeks old improved indigenous (Kienyeji) chicken Farming period: 6 weeks Feeding days: 6 weeks from 4–10 weeks Sensory method: A 7- point hedonic scale was carried out Number of assessors: 12 trained panelists Test sample: Chicken breast and thigh Sample preparation: Skinless breast and thigh were boiled for 30 min without adding any salt and spice. The cooked samples were cut into cubes for evaluation Results: No significant differences were found among samples from all treatments. However, acceptance of the meat increased by the application of EGM in the chicken diet

ID ingredient

Table 3 (continued)

No	Type of ingredient	Methods and Results
17	Black soldier fly (*Hermetia illucens*) larvae meal (BSFM) *Ref* Cullere et al. 2019	Avian species: Broiler quail Farming period: 29 days Feeding days: 19 days from 10–29 days of age Sensory method: A 10 point numerical and continuous scales from 0 (the lowest score) to 10 (the highest score for each attribute) was used Number of assessors: 8 trained panelists Test sample: Quail breast Sample preparation: Frozen quail breast were defrosted for 16 h at + 4 ◦C. Each sample was heated on a baking sheet for 5 min on each side until the core temperature reached 74 °C Results: The use of BSFM in broiler quail had no effect on the odor, flavor and texture of the breast meats
18	Black soldier fly (*Hermetia illucens*) pre-pupae meal *Ref* Pieterse et al. 2019	Inclusion levels: 0,5,10,15% Avian species: 1-day old Cobb 500 Farming period: 35 days Feeding days: 35 days Sensory method: Descriptive sensory analysis (DSA)was used Number of assessors: 8 trained judges Test sample: Chicken breast Sample preparation: Left side breast meats were put in a coded oven bag. They were placed in a pre-heated conventional oven at 160 °C until to reach an internal temperature of 75 °C. The samples were left to cool for 15 min. Each cooked breast was then cut into sample cubes of 1 cm^3. Each cube was wrapped in aluminum foil and placed into three-digit coded heat proof glass cups Results: Inclusion black soldier fly pre-pupae meal in the diet did not affect the chicken odor and flavor, metallic odor and flavor, juiciness, and tenderness of cooked breast samples among the treatment significantly
19	Black soldier fly (*Hemetia illucens*) oil (BSFO) *Ref* Kim et al. 2020	Inclusion levels: 0, 50 or 100% replacement of soybean oil with BSFF Avian Species: Ross 708 Farming period: 35 days Feeding days: 35 days Sensory method: A 7- point hedonic scale was used Number of assessors: 6 panelists Test sample: Chicken breast Sample preparation: Chicken meat was heated 8 min at 80 ˚C until the core temperature researched 74 ˚C. Then samples were presented to the panelists Results: The chicken breast meat fed BSFO had similar sensory attributes compared to the control treatment
20	Earth worm (*Eudrilus eugeniae*) meal (EWM) *Ref* Nalunga et al. 2021	Inclusion levels: 1, 3, and 5% to substitute fish meal Avian Species: Cobb 500 Farming period: 6 weeks Feeding days: 6 weeks from 4–10 weeks Sensory method: A 7- point anchored hedonic scale was implemented Number of assessors: 10 trained panelists Test sample: Chicken breast Sample preparation: Breast samples were cut into 12 mm thickness slices, vacuum packed and boiled for 50 mm without adding salt or any spices to the meat Results: No significant difference was found among meat samples from all treatments. The results also revealed that increasing incorporation of EWM in the chicken diet improved sensory scores in both juiciness and flavor attributes

Table 3 (continued)

No	Type of ingredient	Methods and Results
21	Yellow mealworm (*Tenebrio molitor*) larvae meal *Ref* Šťastník et al. 2021	Inclusion levels: 2 and 5% to substitute fish meal Avian Species: Ross 308 Farming period: 50 days Feeding days: 26 days Sensory method: A graphic non-structured line scale (10 cm; 0 = the worst, 10 = the best) was used to evaluate odor, flavor and fatty flavor, color, juiciness, chewiness and fibriness of the samples Number of assessors: a panel of 10 trained panelists Test sample: Chicken breast and thigh Sample preparation: Chicken breast and thigh were separately heat-treated in a convection oven at 200 °C, 60% humidity for 1 h, and presented to the panelists Results: No significant difference was reported among all breast and thigh samples. Juiciness and flavor attributes were improved by increasing incorporation of yellow mealworm larvae meal in the chicken diet
22	Freeze-dried Mealworm (*Tenebrio molitor*) (FDM) *Ref* Shaviklo et al. 2021a	Inclusion levels: 0, 1, 2, 3% Avian Species: Ross 308 Farming period: 42 days Feeding days: 24 days from 1–24 days Sensory method: QDA with an unstructured 15 cm line scale was implemented Number of assessors: 5 expert panel Test sample: Chicken breast Sample preparation: 50 g of chicken breasts from each treatment were placed in a glass jar containing 100 g distilled water separately. Jars were put in hot water and were heated at 65 ± 5˚C for 60 m Results: Feeding broilers with FDM for 24 days influenced sensory attributes of cooked chicken meat. There were significant differences among treatments in odor and flavor of chickpea, juicy texture, and their acceptance. Control had the lowest level of odor and flavor of chickpea and the highest was seen in the birds fed with 3% FDM. The control sample was juicier and had the highest liking score among the treatments. All these defects were not observed after 42 days of rearing period except for juiciness. The treatment fed with 3% FDM obtained the lowest score of juiciness. Control and treatments fed with 1 and 2% FDM had a similar score of juiciness. However, all treatments had similar acceptance on day 42

and reported that these levels of ingredients did not influence the sensory attributes of eggs significantly ($p < 0.05$). In another study (Bejaei and Cheng 2020) applied full fat dried black soldier fly larvae to feed brown layer pullets for 17 weeks. Inclusion levels (10 and 18%) did not change the sensory quality of eggs ($p > 0.05$), but the intensity of orange color was lower than the control treatment ($p < 0.05$).

The MB products

Fishery and aquaculture processing by-products include the rest of the raw materials of fish and marine crustaceans that are created after processing (filleting, canning, and packaging). These compounds are very nutritious and are commonly used to produce fishmeal and oil, fish protein hydrolysate (FPH) and silage to feed animals. However, these by-products are not fully utilized and this leads to economic and environmental problems in disposing of them. The proximate analysis and nutritional value of fishery by-products is considerable, and depends on different aquatic species (Etemadian et al. 2021). Different fish products are used in animal farming. Figure 2 illustrates the schematic processing methods of these products.

Fishmeal and oil

Fishmeal is a ground brown powder, which obtained after cooking of whole fish/ fish by-products, then dewatering or pressing, drying and milling. In countries where fishmeal is the cheapest animal protein, its use in poultry feed at the

Table 4 Summary of studies implemented in the recent decades indicating effects of MB and ID ingredients on sensory attributes of poultry eggs

No	Type of ingredient	Methods and results
MB ingredients		
1	Menhaden fish oil *Ref* Van Elswyk et al. 1995	Inclusion levels: 0, 0.5, 1.5, and 3.0% Avian Species: 36 weeks old White Leghorn laying hens Farming period: 4 weeks Feeding days: 4 weeks Sensory method: Spectrum method was used to detect flavor intensity using an intensity scale of 0 = not present, 1 = slightly, 2 = moderately, 3 = strongly Number of assessors: 12 trained panelists Test sample: Chicken egg Sample preparation: Eggs were broken into a numbered bowl and stirred with a wire whisk. Eggs were cooked for 4 min in a pre-heated non-stick electric skillet at 122 °C. about 25 g scrambled egg was served immediately following cooking in coded paper cups Results: Fishy odor, sweet taste, fishy and medicinal flavors, and fishy aftertaste attributes were affected by level of dietary fish oil. The medicinal/ chemical taste score was greater in eggs from hens fed 3.0% fish oil as compared to those from control and 0.5% fish oil egg samples
2	Marine microalgae (MA) *Ref* Herber-Mcneill and Van Elswyk et al. 1998	Inclusion levels: 2.4, 4.8% Avian Species: 56 weeks old Single Comb White Leghorn (SCWL) hens Farming period: 4 weeks Feeding days: 4 weeks Sensory method: A nine point hedonic scale was used Number of assessors: 30 untrained panelists Test sample: chicken egg Sample preparation: Blended egg samples were cooked, without mixing, to an internal temperature of 78 ˚C in a nonstick skillet. No seasonings or oil was added to the eggs during preparation. Egg samples were cut into 1 cm^3 pieces for evaluation Results: Eggs from hens fed both levels of MA and the control received acceptable flavor scores
3	Deodorized menhaden fish oil Ref González-Esquerra and Leeson 2000	Inclusion levels: substitution of animal-vegetable blend fat with either regular fish oil or 2.4 or 6% deodorized oil Avian Species: 19 week of age Comb White Leghorn Shavaer pullets Farming period: 55 weeks of age Feeding days: 36 week Sensory method: A 15- point hedonic scale was carried out Number of assessors: 35 untrained panelists Test sample: Chicken egg Sample preparation: Eggs were boiled for 15 min and kept in warm water (35 ˚C) until they were presented to the panelists Results: The incorporation of 2% dietary regular fish oil decreased the sensory attributes of hard-boiled eggs. Eggs produced from hens fed deodorized fish oil had the same sensory attributes including aftertaste and off-flavors. The deodorization process of fish oil did not prevent sensory changes even with just 2% deodorized fish oil in the hen's diet

Table 4 (continued)

No	Type of ingredient	Methods and results
4	Concentrated defatted salmon silage and fish oil *Ref* Kjos et al. 2001	Inclusion levels: 5% fish silage and 0.18, 0.88, 1.68 and 2.48% fish oil Avian Species: 22 weeks old laying hens (White Leghorn) Farming period: 56 days Feeding days: 56 days Sensory method: A 9-point hedonic scale was used Number of assessors: 11 trained panelists Test sample: Chicken eggs Sample preparation: The egg samples were boiled for 10 min and then cooled in cold water for 5 s before sensory analysis Results: Application of fish oil in laying hens diet affected the whiteness of albumin and created an off-flavor in the egg yolk. Feeding with 1.68% fish oil provided the highest intensity of albumin whiteness. Panelists detected the fishy flavor in egg yolks from hens received 2.48% fish oil. There were no significant differences in any of the sensory attributes between egg samples stored at 4 °C for 7 and 35 d
5	Shrimp head meal (SHM) *Ref* Carranco-Jáuregui et al. 2006	Inclusion levels: 0,10,15,20 and 25% SHM inclusion into sorghum-soybean diet Avian Species: Isa Babcok-B-300 laying hens of 42 week of age Farming period: 28 days Feeding days: 28 days Sensory method: The preference test was used to evaluate yolk color. Hedonic test was carried out for egg flavor Number of assessors: 30 untrained panelists Test sample: Chicken egg Sample preparation: Sensory evaluation was done on fresh egg Results: No significant differences were noted for egg flavor and yolk color among 5 treatments
6	Marine fish oil *Ref* García-Rebollar et al. 2008	Inclusion levels: 1.5 and 1.7% fish oil compared to linseed oil treatment (0.1,0.2,0.3,0.4 & 0.5%) Avian Species: 44 weeks old ISA Brown laying hens Farming period: 21 days Feeding days: 21 days Sensory method: A 10 point hedonic scale (dislike = 0 and like = 10) for liking and the other one the intensity of off-flavors and aftertastes (from absent = 0 to very strong = 10) were used Number of assessors: 15 experienced panelists Test sample: Chicken egg Sample preparation: The eggs were maintained at 5 °C for 14 d and then boiled for 15 min. They were kept in warm water until they were evaluated by the panelists Results: No significant differences were observed in the sensory attributes of eggs among treatments or between treatments (control, fish oil treatments and linseed oils (0.1–0.5%) treatments)

Table 4 (continued)

No	Type of ingredient	Methods and results
7	Microencapsulated fish oil *Ref* Lawlor et al. 2010	Inclusion levels: 0, 2, 4, 6% Avian Species: Single-Comb White Leghorn laying hens (Hy-Line W36) Farming period: 21 days Feeding days: 21 days Sensory method: An unstructured 10 cm line scales anchored at both ends (at 5 and 95%) with extremes of each attribute was used Number of assessors: 8 experienced panelists Test sample: Chicken egg Sample preparation: 1) Eggs were boiling in hot water for 12 min, and then cooled to an external temperature of approximately 22 °C using running water. Shells were immediately removed and each egg, cut through the center into quarters, and 5 g samples were weighed (2.5 g of yolk and 2.5 g of egg white per sample). 2) For scrambled egg cooking, eggs were thoroughly mixed, a portion of it poured into a pre-warmed Teflon coated anti-adhering pan and cooked for 1 min on a cooker with continuous stirring. No cooking oil or salt were used Results: Even at the highest level of Microencapsulated fish oil use, slight sensory effects were observed on the sensory properties of boiled eggs, but this is not the case for scrambled eggs
8	Fish oil made from processing by-products (head, bone structure, fins, tissue, and visceral residue) in the industrial scale *Ref* Brelaz et al. 2019	Inclusion levels: 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5% fish oil in the diets, Avian Species: 29 weeks old Hisex White laying hens Farming period: The experiment period lasted 105 days divided into five periods of 21 days Feeding days: 21 days Sensory method: A 9-point hedonic scale was used Number of assessors: 45 untrained panelists Test sample: Chicken egg Sample preparation: Eggs were boiled in hot water for 10 min. Half egg of each treatment was presented for evaluation Results: Significant differences were reported in flavor. Eggs from birds fed diets up to 2.0% of fish oil showed better acceptance by the panelists. Acceptance of the eggs was decreased above this level. The inclusion level of 2.0% of fish waste oil provided eggs with better flavor
ID ingredient		
9	Black soldier fly (*Hemetia illucens*) (BSF) Larva meal *Ref* Al-Qazzaz et al. 2016	Inclusion levels: 0.5% and 1% Avian Species: Laying hens of Arabian strain at nine months' old Farming period: 3 months Feeding days: 3 months Sensory method: A 9 point hedonic scale was used Number of assessors: 30 untrained panel Test sample: chicken egg Sample preparation: Egg were boiled for 10 min and left to cool at room temperature. The eggs were peeled and cut into quarters in white plate Results: The appearance, flavor, texture and the acceptance of eggs were improved by increasing level of BSF larvae meal. The result revealed no significant differences in egg odor between BSF larvae meal fed treatments

Table 4 (continued)

No	Type of ingredient	Methods and results
10	Defatted black soldier fly (DBSF) larvae meal *Ref* Dalle Zotte et al. 2019	Inclusion levels: 10%, 15% Avian species: Six-month-old laying quails (*Coturnix coturnix japonica*) Farming period: 6 weeks Feeding days: 6 weeks Sensory method: A descriptive sensory analysis was carried out Number of assessors: 10 expert panelists Test sample: Quail's eggs Sample preparation: The quail's eggs were boiled for 5 min, cooled by placing them under tap water, then peeled, and the yolk was separated from albumen and then evaluated Results: Incorporation of DBSF larvae meal did not influence the sensory attributes of egg significantly
11	Full-fat dried black soldier fly larvae (DBSFL) *Ref* Bejaei and Cheng 2020	Inclusion levels: 0, 10 and 18% Avian Species: Commercial brown layer 18 weeks old pullets (Novogen Brown) Farming period: 35 weeks Feeding days: 17 weeks Sensory method: Descriptive sensory analysis was used on week-17 of the experiment. The colour, texture, taste and intensity of flavor egg white and egg yolk were evaluated Number of assessors: 6 trained panelists Test sample: Chicken eggs Sample preparation: Eggs were boiled for 13 min. Then they were immediately chilled in cold water and presented to the panelists after peeling Results: Inclusion DBSFL did not influence any of sensory attributes except yolk color significantly. The intensity of orange color in control egg yolk was higher than eggs from chickens fed DFBSF

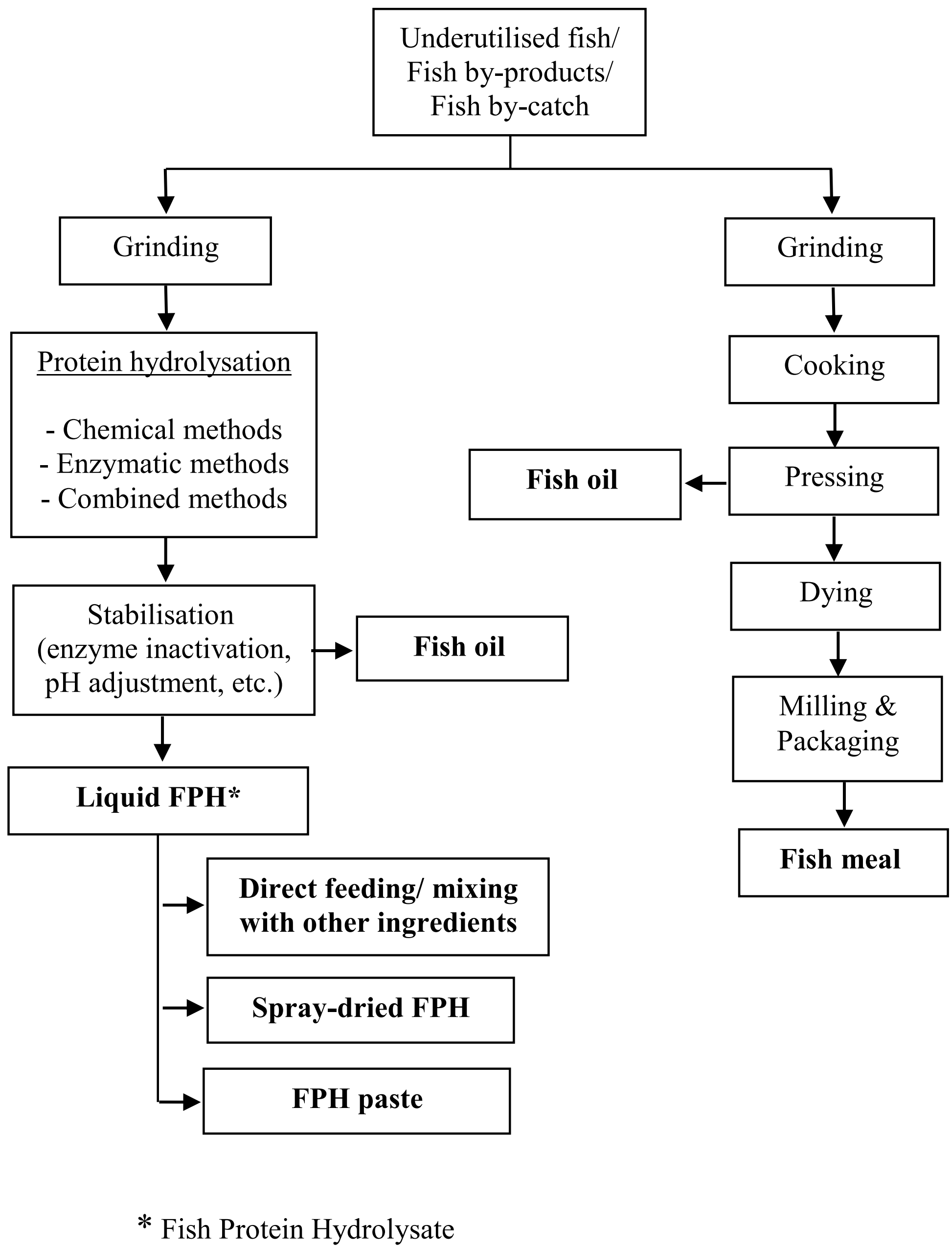
highest possible level is economically viable if the level of inclusion do not change the sensory quality of meat and eggs (Onsongo et al. 2018). Egg fortification with fish oil can influence sensory attributes, which affect consumer liking or preference (Fraeye et al. 2012). The severity of some adverse sensory characteristics such as fishy odor and sourness increases in the yolk as the amount of fishmeal and oil in the diet increases (Lawlor et al. 2010). Accordingly, to prevent fish odor and flavor in the product, it is suggested to use less than 1% fish oil and 12% fishmeal in the poultry diet (Leskanich, and Noble 1997).

FPH

The FPH is a product of breakdown of proteins that contains a mixture of polypeptides, peptides and amino acids. Enzymatic hydrolysis is one of the most important methods used for this purpose. FPH is a balanced amino acid and has a high level of essential amino acids that are extracted from various species of fish. This product can be included in poultry diet as an alternative to fish and soymeal. In addition, FPH improve protein digestibility. Commercial products of FPH are in powder, paste and liquids. The FPH is a valuable source of protein in human food and animal feed, especially for chickens (Etemadian et al. 2021).

Fish silage, a chemical treated form of FPH is a stable semi-liquid product that requires less investment and technology for manufacturing. It is a good substitute of fishmeal or soybean flour as a source of animal protein in regions where there are low-cost fish or sufficient fish processing by-products (Al-Marzooqi et al. 2010). Qiao et al. (2002) reported that using fish silage improves the growth efficiency of broilers, but sensory panelists recognized the unpleasant fish flavor in poultry meat fed 30% fish silage ($p < 0.05$). As it was mentioned, fish oil is the most important factor affecting sensory attributes of animals including chicken meat. Residues of fat in FPH including fish silage can may adversely influence the meat sensory quality (Ramírez et al. 2013). However, carcass discoloration is observed when fish products exceed the desired levels in the poultry diet ($p < 0.05$). In general, up to 20.5 of soybean meal can be substituted with fish silage in chicken nutrition without influencing the performance and sensory quality of the meat (Al-Marzooqi et al. 2010).

Fig. 2 Schematic processing methods of marine based ingredients



Seaweed

Seaweed is a biologically active compound that can be used to feed poultries. The brown seaweed is mostly used in poultry nutrition. Several species of brown, red and green species are used in livestock feeding. Seaweeds are suggested as feed ingredients because of their high content of micro-and macroelements and they can contribute in the growth and performance of poultries and the quality of produced meat and egg quality (Michalak and Mahrose 2020). Seaweed polysaccharides have probiotic activities and can enhance poultry health and performance and improve egg quality. Seaweed can also be used in laying hens and broilers feed to fortify eggs and chicken meat with omega-3 fatty acids (Zeweil et al. 2019).

Microalgae can partially replace soybean meal, corn, sorghum and mineral salts in poultry diet. The level of seaweed incorporation influences the chicken carcass quality. Significant color changes ($p < 0.05$) from yellowish to reddish when 5–15% of *S. muticum* was included in diet was reported (Erum et al. 2017). Athis Kumar (2018) reported that flavor, color, tenderness and juiciness of chicken meat which broilers received 1% or 2% of *Sargassum wightii* scored the highest sensory liking by the consumers ($p > 0.05$).

El-Deekx et al. (2009) reported that the breast muscle color was not influenced when male broiler chicken (Ross) which fed 3% of the seaweed by any dietary treatment ($p > 0.05$). Seaweed at the levels of 15% and 5 and 10% improved the texture of breast and thigh meats significantly ($p < 0.05$). No significant differences ($p > 0.05$) in the odor, flavor, juiciness and color of meat was observed (Michalak and Mahrose 2020).

The maximum level of seaweed in the diet of laying hens is 10% (Carrillo-Dominguez et al. 2008). Seaweed carotenoids can increase the pigmentation of egg yolk. Significant increasing ($p < 0.05$) of the total carotenoids in egg yolks when incorporating brown algae (*sargassum dentifebium*) at level of 3 and 6% was reported (Michalak and Mahrose 2020). Feeding chickens with seaweed can improve the physical and biochemical quality of eggs. The weight, quality of egg shell, including its thickness and strength are important indexes for poultry farmers as well as consumers. Consumers prefer eggs with golden yolks (El-Deek et al. 2009).

Few studies are available on the use of microalgae oil in the laying hen's diet, the results of which indicate the effect of this ingredient on the sensory properties of eggs (Feng et al. 2020). However, excessive use of algae has a negative effect on the egg sensory quality (Al-Marzooqi et al. 2010). Carrillo-Dominguez et al. (2008) reported that the application of 10% *Macrocystis pyrifera*, and *Sargassum sinicola* and 2% sardine oil to the diet did not influence egg flavor ($p > 0.05$). In another research, no significant difference ($p > 0.05$) was detected for eggs flavor produced from the hens received 2.4% marine macroalgae in comparison to the control treatment (Herber-McNeill and van Elswyk 1998). Rendón et al. (2003) revealed that egg flavor was not influenced by the incorporation of post extraction residue from *Macrocycstis pyrifera* at the level of 5% in poultry feed ($p > 0.05$). Eggs from laying Japanese quails received dried *Ulva fasciata* (1.5%) and *Sargassum cinereum* (3%) in their diet had better physical and sensory quality like egg yolk weight, color index and eggshell thickness (Zeweil et al. 2019).

Conclusions

The ID and MB products show great potential for animal feeding to overcome animal feed shortages and to provide animal proteins. The ID and MB products are good sources of nutrients for poultry feeding that can be partially replaced by soybean meal, corn and fishmeal. However, using such ingredients, in poultry diet, influences the sensory properties of meat and eggs negatively or positively. Researchers have used different ratios of these ingredients in the poultry diet studied and other components of the diet have not been the same in all researches. Therefore, the results of the similar studies cannot be compared. But the levels of using these compounds and perceived sensory attributes can be used as guidelines for other researchers and industry to determine the optimum level of inclusion of such products and using them in a stable manner. Information on metabolism of these products in the poultry's body and the end products responsible for their effect on sensory quality of meat and egg, is an interesting topic for further research in this field of study. Furthermore, the provided sensory data could be used in the commercial application of the ID and MB ingredients in poultry nutrition.

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Availability of data and materials All data generated or analysed during this study are included in this article.

Declarations

Conflict of interest The author declares no conflict of interest.

Consent to participate The author has done this study with complete satisfaction.

Consent for publication The author consents to the publication.

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