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Black Soldier Fly Larvae Meal as Alternative Fish Feed Ingredient in Aquaculture

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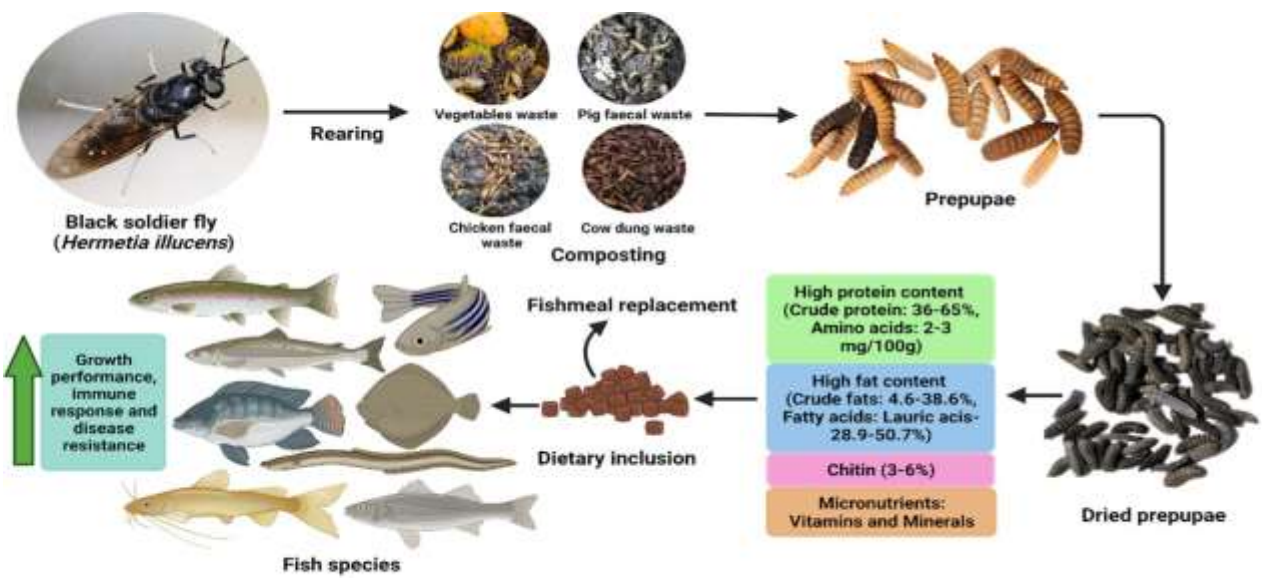
SUMMARY

The demand for alternative protein sources in animal feeds, particularly in aquaculture, has intensified due to increased demand for fish and soybean meal. Insect-based feeds are being considered as viable alternatives, with particular attention on the black soldier fly (BSF), Hermetia illucens. BSF larvae offer a promising solution due to their ability to thrive on organic waste materials, reducing waste volume significantly. They boast a protein content of around 42% and a fat content of up to 35%, making them a valuable source of nutrients. However, there is limited information on their suitability for carnivorous cold-water fish species. This study explores the nutritional characteristics of BSF larvae, including their protein, amino acid, and fatty acid compositions. It also discusses BSF larvae production techniques and their potential as a substitute in fish feed formulations. Various studies have shown that BSF larvae meal can replace conventional protein sources in fish diets without compromising growth performance. Furthermore, the cost-effectiveness of BSF larvae production, coupled with their sustainable utilization, presents a promising avenue for enhancing food security and supporting ecological balance in aquaculture.

INTRODUCTION

The growing demand for fish and soybean meal in livestock and aquaculture feeds has made the animal feed sector more worried about alternative protein carriers. Apart from the EU Regulation (EC) 56/2013, which allows animal leftovers of non-ruminant origin to be used in aqua feeds, producers of fish feed, scientists, and legislators are discussing the usage of insect-based feeds more and more. Hermetia illucens, commonly known as the black soldier fly (BSF) and prevalent in warm and temperate regions circumpolar, was a great option (Bondary and Sheppard, 1981). Because of their capacity to develop on a wide range of organic waste materials, the larvae of this species can reduce trash volume by 50%. According to Sheppard et al. (1994), biomass produced by this growth has a protein content of around 42% and a fat content of up to 35%. While several warm-blooded fish species have shown that BSF larval meal is a suitable source of protein for feedstuff (Bondari, Sheppard, 1981),



there is not enough information available regarding carnivorous cold-water species, including trout and turbot (Kroeckel et al. 2012; St-Hilaire et al. 2007). This report presents the feeding trial results for rainbow trout fed two BSF-larvae meals with organic ingredients.

Black soldier fly larvae's nutritional characteristics and body composition

Early research indicates that the BSFL is the greatest resource for recycling organic wastes into premium feeds and valuable biomass. The BSF larvae's proximate composition, which includes protein, lipids, and carbohydrates, varied greatly depending on the organic materials they consumed. Among the many organic waste types employed in BSF larval rearing are fruit and vegetable wastes as well as manure from pigs, cows, and chickens. Crude protein makes up 50%–60% of BSFL's body, with lipids and amino acids making up the remaining 30%–35% (Tomberlin et al., 2002; Liu et al., 2017). The maximum proportion of crude protein was discovered to be present in five-day-old (BSFL) larvae (61%) with a steady drop in protein content observed with increasing age (Rachmawati Buchori et al.,2010.,

Protein composition

The BSF has a somewhat greater crude protein (CP) content than other insects that have been utilized to make animal feeds, such mealworm beetles (Tenebrio molitor), crickets (Gryllus campestris), drone flies (Eristalis tenax), and beetles. Previous studies have reported that BSF larvae can contain up to 64% protein (St-Hilaire et al., 2007a; Zheng et al., 2012). The larvae's body composition is mostly determined by the quantity and quality of substrate they consume. Protein levels were higher in larvae fed swine dung (43.6%) than in larvae fed cow manure. Furthermore, the crude protein content of BSF larvae is influenced by the processing method. Higher CP concentrations have been seen when comparing fully fattened larvae to partially fattened and defatted larvae

Crude protein, crude fat, ash and amino acids contents of black soldier fly larvae.

CP %	CF %	Ash %	Amino acids % DW						References
			LYZ	MET	THR	ARG	VAL	ILE	
36.2	19	9.3	2.75	0.54	1.95	2.98	2.28	2.1	Barroso et al., 2014
55.3	18	9.9	2.1	0.65	1.7	2.2	2.7	1.9	De Marco et al., 2015
54.8	15.6	7.7	2.1	0.66	2.04	1.73	3.8	2.38	Cullere et al., 2016
39.9–43.1	21.8–38.6	2.7–19.7	2.34–2.57	0.71–0.87	1.54–1.68	1.99–2.03	2.41–2.82	1.72–1.91	Spranghers et al., 2017
62.7	4.7	8	4.14	1.33	2.37	n.d.	5.13	3.18	Marono et al., 2017
43.6	33.1	15.5	2.62	0.74	1.78	2.65	2.79	2.03	St-Hilaire et al., 2007b
57.5	7	n.d.	3.3	0.92	2.32	2.79	3.47	2.44	Mwaniki et al., 2018
32	37.1	19	2.3	0.60	1.49	1.96	2.4	1.47	Caligiani et al., 2018
14.6	2.8	14.7	2.22	0.58	1.42	1.94	2.25	1.57	Kawasaki et al., 2019
42	36.2	n.d.	6.45	2.72	4.48	5.22	5.80	5.08	Huang et al., 2019
23.8	3.1	6.4	5.92	1.60	3.92	4.80	5.68	4.16	Tschirner and Simon, 2015
39.2	28.4	8.3	2.32	2.24	1.84	2.05	1.87	1.56	Liu et al., 2017
17.20	5.83	n.d.	1.22	4.51	3.91	3.43	8.09	1.12	Marco et al., 2021
41.1	n.d.	9.3	4.1	6.1	2.2	1.1	7.2	1.6	Shumo et al., 2019

n.d. – Not detected, CP- Crude protein, CF- Crude fat, LYS- Lysine, MET – Methionine, THR – Threonine, ARG – Arginine, VAL - Valine, ILE – Isoleucine

(Schiavone et al.,)

Crude protein contents in raw BSF (*H. illucens*) compared to mealworm beetle (*Tenebrio molitor)*, cricket (*Gryllus campestris*) and Drone fly (*Eristalis tenax)*, (g/100 g dry matter)

Insect	Crude protein	References
Mealworm beetle (*Tenebrio molitor*)	38.3	Kuntadi *et al.*, 2018
Cricket (*Gryllus campestris*)	32.6	Kuntadi *et al.*, 2018
Drone fly *(Eristalis tenax)*	40.9	Barroso *et al.*, 2014
BSF (*H. illucens*)	42.0	Huang *et al.*, 2019

Amino acid composition

Variations in body composition have been noted according on the culture substrates employed, and the BSFL provides an abundant supply of amino acids. Significant amounts of amino acids have been found in the BSFL fed cow manure (St-Hilaire et al., 2007a; Al-Qazzaz and Ismail, 2016; Kim et al., 2021). The amino acids alanine, arginine, aspartic acid, cystine, glutamic acid, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, and tyrosine have been shown to be present in BSFL, according to studies conducted by Makkar et al. (2014) and Shumo et al. (2019).

Fatty acids composition

According to Kroeckel et al. (2012), the average content of mono and polyunsaturated fatty acids (PUFAs) in BSF larvae is 19%–40%, whereas the concentration of saturated fatty acids is 58%–72%. Growing BSF larvae on an organic substrate supplemented with 10% Schizochytrium sp. resulted in a significant increase in the PUFA content of the insects. Studies have shown that BSF prepupae biomass is enhanced when an organic substrate with the appropriate concentrations of PUFA is used. This indicates that the growth substrate used has a significant impact on the nutritional quality of BSF biomass. Above all, in BSF larvae generated utilizing coffee silver skin by product augmented with (10% W/W) Schizochytrium sp., the content of PUFAs in BSFL biomass was considerably raised (Zarantoniello et al., 2020). A separate research states that triglycerides make up the majority of the lipid content of BSFL, which ranges from 8% to 60% of its dry weight (Caligiani et al., 2019). Lauric, palmitic, α-linolenic acid—also referred to as eicosapentaenoic acid—and oleic acid are among the fatty acids from the BSFL that have been reported to exist (Surendra et al., 2016; Starcevic et al., 2019). The only things that alter the amount of fatty acids are the feed given to the larvae and the nutritional value of the food.

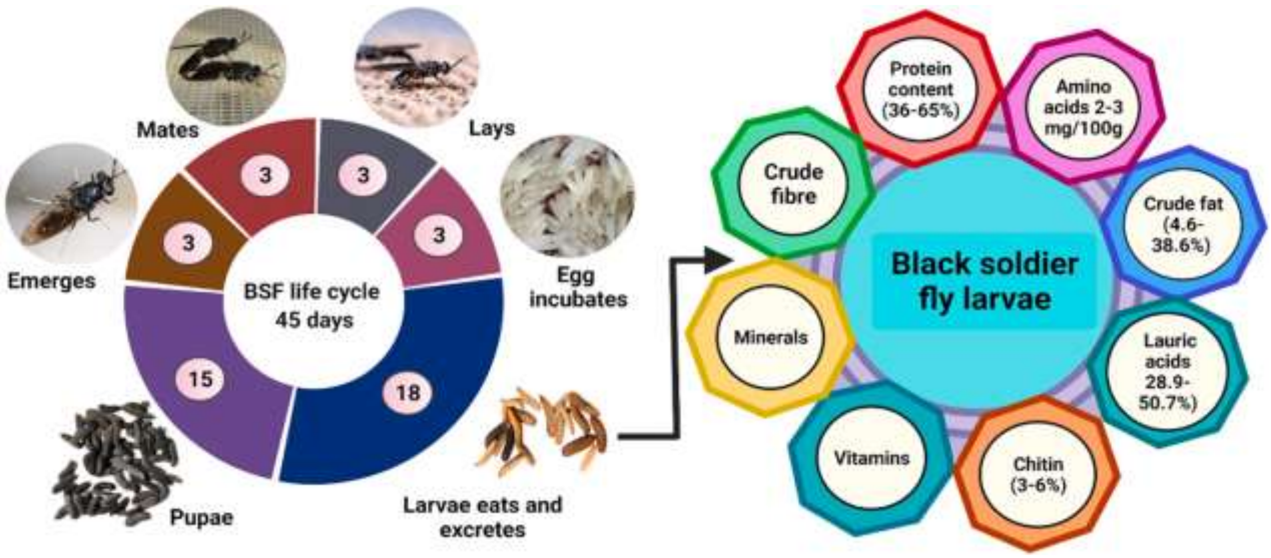
Fatty acid contents of black soldier fly larvae.

Fatty acid contents (%)															References
12:00	14:00	16:00	18:00	16:1n-7	18:1n-9	18:2n-6	18:3n-3	20:5n-3	22:6n-3	SFA	MUFA	PUFA	Ω-6	Ω-3	
0	2.4	16.6	43.5	2.2	0	0	0	0	0	65.8	32.6	1.1	1.1	0	Barroso et al., 2014
14.4	3.3	16	25.1	2	23.9	4.99	24.3	0.2	3.2	0	0	0	0	28.5	Spranghers et al., 2017
14.1	1.9	5.3	0.9	1.1	7.3	2.7	0.2	0.3	0	22.9	8.6	3.2	0	0	Kawasaki et al., 2019
61.4	10.2	7.8	1	2.5	0.1	7.2	0.4	0	0	0	0	0	0	0	Liu et al., 2017
41.96	7.05	18.02	3.68	5.82	17.93	57.25	3.19	0	0	0	17.7	13.43	0	0	Marco et al., 2021
49.34	6.83	10.48	2.78	3.45	11.81	3.68	0.08	0	0	0	0	0	0	0	St-Hilaire et al., 2007b
7.5	2.3	19.2	6.9	0.8	26.6	31.4	3.6	0	0	36.2	28.7	35	0	3.6	Ewald et al., 2020

12:0-Lauric Acid; 14:0-Myristic Acid; 16:0-Palmitic acid; 17:0-Heptadecanoic acid; 18:0-Stearic Acid; 16:1n-7-Palmitoleic acid; 18:1n-9-Oleic Acid; 18:2n-6-Linoleic Acid; 18:3n-3-Alpha-linolenic Acid; 20:4n-6-Arachidonic Acid; 20:5n-3-Eicosapentanoic Acid; 22:6n-3-Docosahexanoic Acid; SFA- Saturated fatty acids; MUFA- Monounsaturated fatty acids; PUFA- Polyunsaturated fatty acids

Black soldier fly training techniques

The increased requirement for protein fish meal in aquaculture has led to a rise in the usage of insect meal due to its high energy content and nutritional value. The black soldier fly, or H. illucens, is used as a replacement source of protein in aquaculture. Around the world, there are several facilities available for the bulk growth of H. illucens. Black soldier flies are the best source for decomposing organic items including leftover fruits and vegetables. According to Sheppard et al. (2002) and Cannella et al. (2016), H. illucens has a 45-day life cycle that consists of four different stages: eggs, larvae, prepupae, and pupae, or adult flies. an outline of the food, physiology, and life cycle of the black soldier fly.

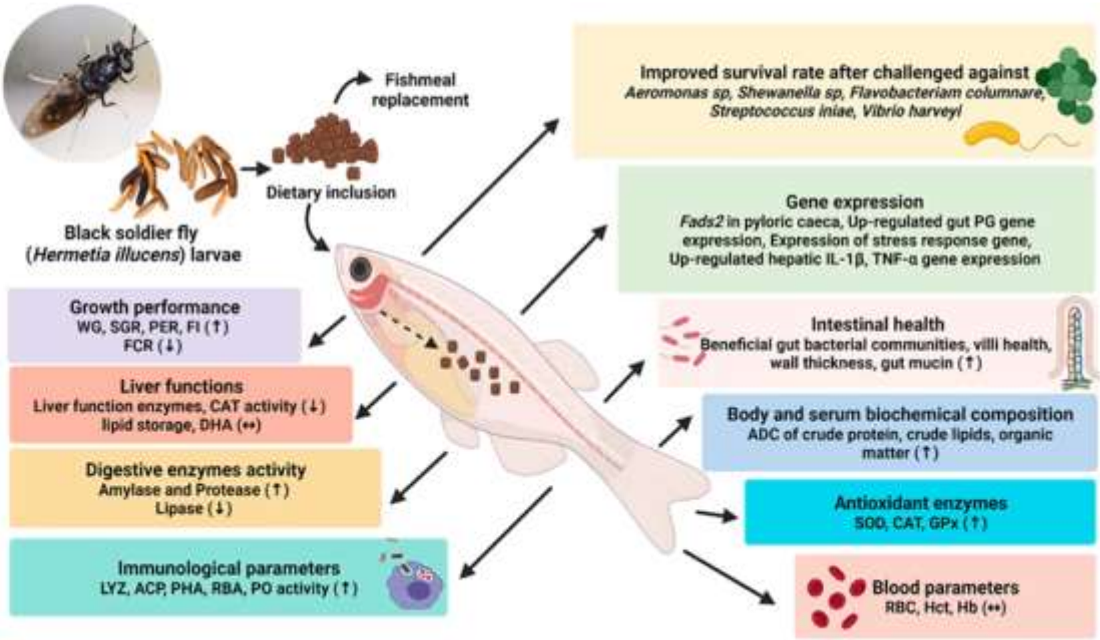


In addition, BSFL have been produced using a variety of rearing substrates. Eggs must hatch in a minimum of 48 hours. Prepupae larvae's dorsal side has a dark brown to black color that may be utilized to identify different growth stages (Sheppard et al., 2002). In another investigation, the optimal temperature for BSFL cultivation was determined and reported. The lifespan of BSFL eggs may vary greatly depending on the temperature. Temperature was shown to alter the eclosion ratio, as evidenced by the low (<11%) eclosion rate of eggs at 15◦C, 37◦C, and 40◦C, and the high (80%) eclosion rate at 30◦C. Moreover, the sole thing that affects the body weight of BSFL larvae is their larval diet.

BSF Larvae Usage in Fish Feed Formulation

Insect meals have been used in fish feed diets for a very long time (Barragan et al., 2017). Because of their exceptional ability to reproduce, short life cycle, ability to convert organic matter into high-quality protein, and adaptability to a variety of settings, BSF larvae have garnered a lot of interest for their use in fish diets (Barragan et al., 2017). Furthermore, the BSF larvae are a common meal choice for fish diets due to their high protein content, digestibility, and amino acid profiles. The BSF meal has successfully replaced other conventional protein sources in the diets of Channel catfish (*Ictalurus punctatus*) (Bondari and Sheppard, 1981, 1987; Zhang et al., 2014a,b), blue tilapia (*Oreochromis aureus*) (Bondari and Sheppard, 1981, 1987), Nile tilapia (*Oreochromis niloticus*) (Muin et al., 2017), O. niloticus crossed with Sabaki tilapia (*Oreochromis spilurus*) (Furrer, 2011), rainbow trout (*Oncorhynchus mykiss*) (St-Hilaire et al., 2007b; Sealey et al., 2011), Atlantic salmon (*Salmo salar*) (Lock et al., 2015), turbot (*Psetta maxima*) (Kroeckel et al., 2012), yellow catfish (*Tachysurus fulvidraco*) (Zhang et al., 2014a) and African catfish (*Clarius gariepinus*) (Adewolu et al., 2010; Idowu and Afolayan, 2013).

The body weight gain (BWG) and specific growth rates (SGR) of O. niloticus did not experience any adverse impacts from the addition of BSF larvae meals to their diets (Devic et al., 2018; Toriz- Roldan et al., 2019). Similar to this, there were no alterations in the BWG and SGR of juvenile Japanese bass (*Lateolabrax japonicus*) and rainbow trout (*Oncorhynchus mykiss*) when FM was partially or completely replaced with BSF larval meal (Wang and Shelomi, 2017; Belghit et al., 2019).In a study on *C. gariepinus*, Fawole et al. (2020) found that when 50% of FM was replaced with BSF larvae, the final weight (19.84g, 14.79g), BWG (15.83g, 10.82g), protein efficiency ratio (1.62, 1.29), SGR (2.66%, 2.19%), and feed intake (23.26, 20.09) were significantly higher than when the control diet which contained 0% BSF larvae meal was administered. Similarly, when BSF larvae meal was substituted for FM in the diets of *O.niloticus* at 0, 25, 50, 75, and 100%, Muin et al. (2017) reported the greatest weight growth and SGR values of 8.74 and 2.43%, respectively. Furthermore, at a 25% inclusions level, BSF meal has been demonstrated to be a good substitute for fish meal in the diets of Pacific White Shrimp (*Litopenaeus vannamei*) (Cummins et al., 2017).Additionally, as compared to traditional feed sources like FM and soyabean meal, the use of BSF larvae in fish diets has demonstrated the ability to reduce production costs. In Kenya, fish meal costs between 1.2 and 1.5 U$D/kg, soybean meal costs between 0.9 and 1.6 U$D/kg, and BSF larvae cost between 0.8 and 1.2 U$D/kg. The cheap cost of feeding BSF larvae, which consume low-value organic wastes, and the ease of use of the culture systems are linked to their low costs (Diener and Trockner, 2009; van Huis, 2013).



An overview of the growth performance of various fish species fed diets including BSF larvae meal. The suggested replacement levels are shown by bolded values.

Fish species tested	Attribute/element tested	Replacement levels (%)	Author (s)
Jian carp (*Cyprinus carpio*)	A study by Li *et al*. 2017 suggested that it is possible to substitute up to 100% FM by BSF larvae meal in diets for Jian carp without negative effect on growth performance and feed utilization efficiencies	0, 25, 50, 75, **100**	Li *et al*. (2017)
Mearger (*Argyrosomus regius*) juvinilles	10% of *Hermetia illucens*, can be included in Meagre diets without major adverse effects on growth, feed utilization, whole-body composition and fatty acid profile, further increase in the substitution rates lead to a negative effect on the growth performance parameters	**10**, 20, 30	Guerreiro *et al*. 2020)
Nile tilapia (*Oreochromis niloticus*)	Replacement of soya protein concentrate by partly defatted BSF larvae meal up to a level of 50% had no negative effect on growth performance and improved the dietary protein quality of tilapia feeds under study	25, **50**, 100	Dietz and Liebert (2018)
Siberian sturgeon (*Acipenser baerii*)	Overall, this study showed that it is possible to replace up to 25% of FM with BSF larvae meal in the diet of Siberian sturgeons (equal to 18.5% HIM inclusion level) without affecting the growth performance	**25**, 50, 100	Caimi *et al*. (2020)
Rainbow trout (*Oncorhynchus mykiss*)	The maximum inclusion of BSF larvae meal recommended in rainbow trout diets is 13% further increase in the substitution lead to a decrease in the growth parameters	0, 6.6, **13.2**, 26.4	Dumas *et al*. (2018)
Nile tilapia (*Oreochromis niloticus*)	The study suggests that substitution of FM with BSF larvae upto 100% is possible without any negative effects on the growth performance, feed utilization efficiency, body composition	0, 25, 50, 75, **100**	Muin *et al*. (2017)
European sea bass (*Dicentrarchus labrax*)	With the 3 substitution levels of FM with BSF larvae meal at (25, 35, 50 %), BSF larvae meal can effectively replace FM upto 50% without any negative effects on the growth performance	25, 35, **50**	AbdelTawwab *et al*. (2020)
Rice field eel (*Monopterus albus*)	Lower substitution rates (5.26, 10.52%) of FM by BSF larvae meal in the diets of Rice field eel, exhibited low values of the growth performance parameters as compared to a higher substitution rate of FM by BSF larvae meal made at 15.78%	5.26, 10.52, **15.78**	Hu *et al*. (2020)
African catfish (*Clarius gariepinus*)	Substitution of FM by BSF larvae up to 75% lead to no negative effects on the	0, 25, 50, **75**	Fawole (2020) *et al*.

	growth performance and nutrient utilization		
Juvenille turbot (*Psetta maxima*)	The maximum inclusion of BSF larvae mealrecommended in Juvenile turbot diets is 33% further increase in the substitution lead to a decrease in the growth performance parameters and nutrient utilization	0, 17, **33**, 49, 64, 76	Kroeckel *et al*. (2012)

CONCLUSION

The BSF larvae have a great potential to add high-quality protein to fish diets because of their exceptional nutritional properties, which support healthy growth and reproduction rates. The BSF can be sustainably used to improve fish growth performance, reduce aquaculture production costs, and maximize resource utilization all of which support food security, livelihoods, and ecological balance—by using appropriate culture systems and processing methods, primarily to remove chitin.

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