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CRITICAL REVIEW: ESSENTIAL FATTY ACIDS ON SHRIMP FEEDING

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ABSTRACT - Four types of poly unsaturated fatty acids (PUFA) are essential for all shrimp species, linoleic (LOA, 18:2n-6), alfa-linolenic (ALA, 18:3n-3), eicosapentaenoic (EPA, 20:5n-3) and docosahexaenoic (DHA, 22:6n-3) acids. Moreover, the arachidonic acid (ARA, 20:4n-6), even when present, seems to be, in crustaceans, not so important or yet dispensable. It is relevant knowing that cholesterol as much as PUFA are not well absorbed when not followed by a substantial amount of lecithin, reaching 5% of the ration. The sum of PUFA reaches around 3% of the diet, even varying according to the species, stage and ration type. For *Penaeus monodon*, a complex mathematic model was formulated in order to describe the relationships between the requirements of the cited PUFA. Industries involved with feed production on this segment must possess its own adaptation for another species. On the other hand, biochemical knowledge on PUFA n-3 series compounds functions are yet very delayed in comparison to the advances on pharmaceutical industry that investigates the n-6 series, with its prevalence in humans. In this review, the term PUFA is generically used to include ALA, LOA, DPA, EPA, ARA and DHA.
Key words: aquatic invertebrates, fatty acids, lipids, nutritional requirements, shrimp.

REVISÃO CRÍTICA: ÁCIDOS GRAXOS ESSENCIAIS NA ALIMENTAÇÃO DO CAMARÃO

RESUMO - Quatro tipos de ácidos graxos polinsaturado (PUFA) são essenciais para todas as espécies de camarão, são os ácidos linoleico (LOA, 18: 2n-6) alfa-linolénico (ALA, 18: 3n-3), eicosapentaenóico (EPA, 20: 5n-3) e docosahexaenóico (DHA, 22: 6n-3). Além disso, o ácido araquidónico (ARA, 20: 4n-6), mesmo quando presente, parece ser, em crustáceos, pouco importante ou ainda dispensável. É importante saber que os PUFA não são bem absorvidos quando não seguido por uma quantidade substancial de lecitina, atingindo 5% da ração. A soma de PUFA atinge cerca de 3% da dieta, mesmo variando de acordo com o tipo de espécies, estágio e ração. Para *Penaeus monodon*, um modelo matemático complexo foi formulado de modo a descrever as relações entre os requisitos de a citada PUFA. As indústrias envolvidas com a produção de alimentos desse segmento, devem possuir suas adaptações próprias para outras espécies. Por outro lado, os conhecimentos bioquímicos sobre as funções dos compostos da série n-3 dos PUFA estão ainda muito atrasados, comparado com os avanços da indústria farmacêutica que investiga a série n-6, com prevalência no homem. Nesta revisão, o termo PUFA é genericamente usado para incluir ALA, LOA, DPA, EPA, ARA e DHA.
Palavras-chave: invertebrados aquáticos, ácidos graxos, lipídeos. exigências nutricionais, camarão,

INTRODCTION

Aquaculture is an activity today present on every continent, although 11 of the 17 largest producers are Asian (FAO, 2013). In this context it is interesting to observe that Asian peoples and their American descendants engaged in the creation of aquatic animals possibly from the Paleolithic, but is documented in China 5000 years ago (ZHIWEN, 1999). In South America in pre-Columbian times, there was a landscape reshuffling over several square kilometers in a neighboring land to the Mato Grosso' Pantanal gift, which allowed raising fish in their own habitat, modified to facilitate human use (ERICKSON, 2000). At the same time, and probably since very ancient times, on the other side of the Andes, near the Peruvian coast of the Pacific Ocean, it was made the shrimp cultivation in large ponds created by man by the sea (DENEVAN, 1992).

Under these conditions, considered primitives a short time ago, but judged, now exemplarys in terms of ecological conservation, had still not been discovered that animals need essential factors in their food. Only during the 20th century it was learned that in addition to various vitamins, animals as a whole must have access to many chemical compounds, after present in your body, and sometimes even in large quantities. An extreme case are the proteins, of which the animals can not synthesize half of precursors required, the amino acids (STRYER et al., 2002). These nutritional requirements are decisive in creating, in such a limited confinement that man must provide for the animals daily food in the form of ration.

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Currently, several species of shrimp, are undoubtedly the aquatic invertebrates most cultivated by the large profit they provide, and the shrimp *Litopenaeus vannamei*, already created by the Peruvians and pre-Columbian, occupies today also one of the first places in all aquaculture in terms of production (MONTAÑO; NAVARRO, 1996; ROSENBERRY, 1998; PAHLOW et al., 2015).

Considering lipids that can not miss in food, crustaceans - like many other invertebrates - are deficient not only in the biosynthesis of essential fatty acids. They also need to ingest fat-soluble vitamins and cholesterol, which is produced without problem in all vertebrates, including fish (BARBOSA LIMA; FIGUEIREDO-LIMA, 2016).

The functions of fat-soluble vitamins are much more studied and known in vertebrates than in invertebrates. In fact, if they had not been made research on shrimp needs, encouraged by the commercial interests of aquaculture, hardly exist evidence to prove quantitatively, what the requirements of certain specific species (SHIAU, 1998). It should be noted, however, that the function of fat-soluble vitamins in terms of action mechanism is hypothetical crustaceans, even in these examples, and remains explained by analogy with the knowledge obtained in vertebrates. An extreme example is the function of vitamin D that acts on vertebrates on the mineralization of bones. In crustaceans, nor is there the same organ, but it is undeniable the essentiality of vitamin (NEW, 1976; SHIAU, 1998; GOUILLOU COUSTANS; GUILLAUME, 2001; BARBOSA LIMA; FIGUEIREDO-LIMA, 2016).

Essential fatty acids are undoubtedly the best researched nutritional subject of aquaculture in general and in particular shrimp creation. This interest is explained by the fact that nothing better justifies the consumption of aquatic animals by man, than these animals are the richest source of essential fatty acids.

Four types of PUFA are essential to all species of shrimp, linoleic acid (LOA, 18: 2n-6), alpha-linolenic acid (LNA, 18: 3n-3), eicosapentaenoic acid (EPA, 20: 5n-3) and docosahexaenoic acid (DHA, 22: 6n-3). The preparation of this review came from the study of pioneering works that elucidated the biochemical mechanisms and the importance of lipids for shrimp.

Poly unsaturated fatty acids (PUFA)

PUFA concept and chemical structure

Lipids of every superior organisms contains significant amounts of poly unsaturated fatty acids (PUFA) with double bonds separated by methylene radicals, meaning two or more double bonds of cys configuration separated by a single methylene radical. Acronyms more often used to replace the complicated chemical nomenclature are: "PUFA" from poly-unsaturated fatty acids, "HUFA" from highly unsaturated fatty acids and "EFA" from essential fatty acids. PUFA are subdivided into two groups, fatty acids n-6 and n-3, formerly Omega-6 and Omega-3, respectively, since they have distinct biosynthetic pathways and, possibly, functions. PUFA nomenclature indicates the first double bond position from methyl terminal of carbon chain, this way, fatty acids n-6 present this saturated Bond between carbons 6 and 7, and fatty acids n-3, between carbons 3 and 4. Linoleic acid, for instance, is a n-6 fatty acid, with two double bonds in C-12 and C-9 and is entitled 9c,12c-18:2 or, abbreviated as 18:2 n-6. The main n-6 fatty acids, arachdonic acid (ARA) and docosopentaenoic acid (DPA) are derived from linoleic acid (LOA), and the most important n-3 fatty acids, docosahexaenoic acids (DHA) and eicosapentaenoic acid (EPA) come from alfa-linolenic acid (ALA), since it is achievable to create elongations on LOA and ALA and additional oxidations on the new acids with 20 and 22 carbons. In plants, these long chain compounds do not seem to be necessary. PUFA biosynthesis deficiency was first found by Burr and Burr (1929; 1930) in rats. However indeed, in most of vertebrates and invertebrates fundamental enzymes needed to produce LOA and ALA from oleic acid are lacking, Delta-12 and Delta-15 desaturase, respectively.

Some authors attribute the term PUFA only to ALA and LOA compounds, a HUFA denomination to EPA, DHA, ARA and DPA, and EFA depends on each species (GONZÁLEZ-FÉLIX al et., 2002; 2003a,b). However, we are going to use the term PUFA to include ALA, LOA, DPA, EPA, ARA and DHA.

PUFA biological functions

PUFA prevalence origin in plants, microorganisms, invertebrates and in most of the aquatic animals and the reason for its essentiality in animals in general were unveiled when reflected on the consequences of the liquid membranes model, developed by Singer and Nicholson (1972). In live being without temperature control, membrane would freeze, causing organisms death, if they did not have a high PUFA amount incorporated on its lipids components, that are liquid until temperature close to 0 ºC, and this way, every plant in cold climatic zones and many aquatic animals would be condemned for good, if they did not adapt properly. On the other hand, in every animals, poikilothermic or not, PUFA are released enzimatically from their bonding with polar lipids in the cell plasmatic membrane, to serve as precursors of eicosanoids, universal hormones which form and act within the tissues. Moreover, recently were unveiled two cases that prove another eicosanoids activity, similar to that of steroid hormones, of transforming nuclear receptor into transcription factors, in which they control, united to retinoid, the cellular differentiation (MANGELSDORF; EVANS, 1995; STEINMETZ et al., 2001; BERGER; MOLLER, 2002; WEI, 2003). It is very plausible that this last functional aspect of PUFA might explain the dreadful potency of these compounds on reproduction and ontogenesis, processes of enormous economic interest in aquaculture, yet reserved to great gait institution that are able to invest in breeders and larviculture. However, fattening of juveniles is not an as simple process as it seems to be and involves very complicated processes of tissue differentiation in each molt, directed not only by ecdison, but also by retinoids and perhaps by hormones coming from PUFA (DURICA; HOPKINS, 1996; DURICA et al., 1999).

Metabolism of essential fatty acids in shrimp species

Researches on PUFA essentiality in crustaceans in general and in shrimp species, in particular, fit on Cellular Biology development as interesting alternatives due to its eminently practical aspect and because they provide most of the evidences on this subject in invertebrates. Predominant strategies on the respective research projects were tissue analysis in wild and raised animals, researches on biosynthesis with markers, observation of critical transformations (egg laying, larvae hatching) and so far, mainly studies on weight gain through controlled diets.

The first studies on shrimp growing stimulation through PUFA were carried out by using supposedly riches oils on these compounds, coming from shrimp head, anchovy, sardine, mussels or cod liver. Therefore, positive results were obtained in *Penaeus aztecus* by Shewbart and Mies (1973), in *Macrobrachium rosenbergii* by Sandifer and Joseph (1976), in *P. japonicus* by Guary et al. (1976) and Kanazawa et al. (1977a), in *Palaemon serratus* by Martin (1980) and in *P. indicus* by Read (1981). Nutrition researches were complemented with other methods to substantiate that various PUFA are essential, also, to *P. monodon* and *P. merguiensis* (KANAZAWA et al., 1979d) and to *P. stylirostris* (FENUCCI et al., 1981).

Lipid analysis on shrimp tissues after given nutrition improved the understanding on fatty acids metabolism. This kind of study allowed the conclusion that as much in *P. japonicus* as in *M. rosenbergii*, saturated and unsaturated fatty acids can be formed from palmitic acid (16:0) (KANAZAWA; TESHIMA, 1977; KANAZAWA et al., 1979a), but do not change lately in linoleic (LOA) (18:2n-6), alfa-linolenic (ALA) (18:3n-3), eicosapentaenoic (EPA) (20:5n-3) and docosahexaenoic (DHA) (22:6n-3) acids (KANAZAWA et al., 1977a, 1979e; REIGH; STICKNEY, 1989). Fatty acid profile in *P. setiferus*, *P. aztecus* and *P. duorarum* (BOTTINO et al., 1980) and in *P. indicus* (READ, 1981) indicated that those species have certain capacity to transform C18 PUFA into C$\geq$20 PUFA. Using marked 18:3n-3, Kanazawa et al. (1979b) proved the same biosynthesis in *P. japonicus*. However, although the incorporation research of radioactive precursors is the ideal method to confirm the absence of biochemical transformations, this very same technique does not allow to easily quantify the metabolic flow when a precursor convert itself in another compound. Consequently, it is possible that certain substance present itself as an essential nutrient, in spite of being synthesized in vivo, once its production is not enough to cover the physiological needs in each growing phase. Kanazawa et al. (1978, 1979g) described impressive effects of EPA and DHA on *P. japonicus* growing, in comparison to ALA, although they just had found the referred conversion of ALA into DHA, in the same shrimp species (KANAZAWA et al., 1979b). The suspect that 20:4n-3 and 22:6n-3 poly unsaturated acids can not be sufficiently synthesized from essential precursors was confirmed by Xu et al. (1993) who proved in *P. chinensis* a decrease on nutritive value of fatty acids as followed: 22:6n-3 > 20:4n-6 > 18:3n-3 > 18:2n-6, by evaluating survival, molting frequencies and juvenile growing. In a complementary study, the same authors (XU et al.,1994b) were able to demonstrate, through chemical dosages on *P. chinensis* fat after selective feeding, that this shrimp has not the Ω^6 desaturase, but converts 18:2n-6 into 20:2n-6 and 18:3n-3 into 20:3n-3, proportionally to the precursor level on the experimental ration. Afterwards, Merican and Shim (1996, 1997), studying *P. monodon*, observed again that ALA can not cover the DHA deficiency. However, the ALA requirement depended on the DHA level on feeding. On the other hand, Merican and Shim (1996, 1997) researches with *P. monodon* confirmed previous results of D'Abramo and Sheen (1993) obtained with *M. rosenbergii* that indicated that EPA may be generated by retro-conversion (beta-oxidation) from DHA, which suggests that 20:5n-3 must play an important role that can not be replaced by 22:6n-3. Elongation and dessaturation of ALA (18:3n-3) producing larger n-3 PUFA do not occur in *P. setiferus* and *Macrobrachium rosenbergii* (BOTTINO et al., 1980; D'ABRAMO; SHEEN, 1993), but were observed in *P. aztecus* and *L. vannamei* (ARAUJO; LAWRENCE, 1993; SHEWBART; MIES, 1973). The mentioned rections are modest in *P. japonicus* and *P. indicus* (KANAZAWA et al., 1979b; READ, 1981). However, whilst ALA (18:3n-3) – at least during vigorous growing of juveniles – can not be considered as a precursor of 20:5n-3 and 22:6n-3 in neither shrimp species, becomes an authentic mystery which may be its indispensable function besides structural.

Fatty acid assimilation coming from feeding

As reviewed previously, it is possible to infer that all economically interesting species of shrimp need simultaneously of the four mentioned PUFA. It is useful to reinforce that the conversions cited above may not be present in the same shape in different species, or distinct life cycle stages. Whilst the requirement of each PUFA depend on the bioconversion capacity (enzyme activity), each fatty acid possess nutritive value (energetic yield) that influences the metabolic rate that exceed for the regarding transformations, and yet, may occur inhibitions in anabolic pathways that depend on the available precursor and on the final metabolites concentrations (CASTELL, 1972).

Moreover, the set of reactions that compose the fatty acids metabolism in general is integrated in a bigger system which involves the biochemistry of other substances. Every shrimp species used in aquaculture, due to a non explained metabolic regulation, have limited capacity of using lipids as energy source and, therefore, as nutrient, favoring in exchange, protein catabolism (GLENCROSS et al., 2002c). For aquaculture it would be more economic and ecologically correct to put on weight shrimps with vegetal oil instead of using feedstuff of high protein content. If considering only the release of metabolic energy, the best results should be expected by using oils riches in C-16 ("medium chain triglycerides"). However, studies performed by Deering et al. (1997) with *P. monodon* and by Lim et al. (1997) with *L. vannamei* let no doubt that these oils produce the worst results if not enriched with several PUFA, as seen in papers from the 70's and 80's, previously mentioned, which establish the former knowledge on essential fatty acids in invertebrates. In a few words, the best nutritive results are obtained exactly with those oils of limited accessibility coming from other marine animals.

Every time that it was investigated not only weight gain, feed conversion and other biometric data, but also lipid composition on fed animal, it was observed that the endogen composition greatly reflected the feed composition, above all on triglycerides of hepatopancreas (COLVIN, 1976; GUARY et al., 1976; KAYAMA et al., 1980; PETRIELLA et al., 1984; MILLANEMA, 1989; CATACUTAN, 1991; DALL et al., 1992; XU et al., 1994a,b; MERICAN; SHIM, 1996; GONZÁLEZ-FELIX et al., 2002; 2003a,b). Logically, this conclusion taken from captivity experiences under controlled conditions, should account, also, for wild animals. For these latest, high PUFA concentrations were always found, mainly of those with long chain (EPA, DHA), as never were reached on the same species when cultivated (BOTTINO et al., 1980; O'LEARY; MATTHEWS, 1990; MONTAÑO; NAVARRO, 1996; CAVALLI et al., 2001; WOUTERS et al., 2001a).

In nutrition assays with lipids poor in PUFA, a frequent observation was the accumulation of triglycerides containing palmitic and/or oleic acid (COLVIN, 1976; GUARY et al., 1976; KAYAMA et al., 1980; CATACUTAN, 1991; DALL et al., 1992; XU et al., 1994a,b; MERICAN; SHIM, 1996; GONZÁLEZ-FELIX et al., 2002). At the same time, several researches interpreted their data supposing that there are balances which control the relationship between PUFA and oleic acid and between individual PUFAs. Glencross et al. (2002a,b) found that PUFA must attain a given proportion, not with the diet, but with fatty acids on diet and they could then develop a mathematic model on PUFA requirement which allow to predict quantitatively weight gain and shifts on animal lipids reserve, that will occur due to certain fatty acids combination in nutrition. Glencross et al. (2002a,b) believe that the model success depends on provide feed without satisfying the animal and they devise that formula used to find PUFA requirement do not fit only for *P. monodon*, which served a base for these researches, but that they are universal for most of the aquatic animals, vertebrates and invertebrates.

There is an ingredient that has been largely studied in the context of PUFA assimilation: lecithin, meaning the group of polar lipids that compose this interesting nutrition material (COUTTEAU et al., 1996; COUTTEAU et al., 1997; KONTARA et al., 1997; SHIAU, 1998; GONZÁLEZ-FELIX et al., 2002). This component was found as useful on the first artificial ration for lobster breeding (CONKLIN et al., 1980; D'ABRAMO et al., 1981), Kanazawa used several types of lecithin on *P. japonicus* breeding and some fishes (KANAZAWA et al., 1979f, 1985a,b; TESHIMA et al., 1982, 1986a-e). Japanese and American researchers (D'ABRAMO et al., 1982, 1985a) presented that lecithin and its components, phosphatidilcholine and phosphatidilinositol, stimulated not only cholesterol assimilation, but also, triglycerides' and mainly, PUFA's. It was proved that these effects were not caused by lecithin, acting as emulsifier or choline donator, however it missed to clarify the reason why a synthetic phosphatidilcholine with saturated fatty acids was inactive (KANAZAWA et al., 1985b). In this lecithin usage problem to facilitate lipid digestion, the only great step toward, after decades, was given in a paper from Hadas et al. (2003) in which the absorption of radioactive oleate was investigated in *Sparus aurata* larvae, a largely cultivated fish at the Mediterranean. In a conclusively way, authors proved that phosphatidilcholine did not stimulate intestinal absorption of fatty acid that much, but amplified greatly its assimilation on body tissues and even its catabolism. In larvae without phospholipids on diet, the marker got stuck on gut enterocites (as triglyceride), even in a 10 hours interval of fasting after feeding, and researchers discussed the possibility of animals not even feel hunger by suppression of a neutrophic signal under these conditions. This way it got finally clear as phosphatidilcholine increases lipoprotein production that carry triglycerides to blood circulation and, at the same time, to body metabolism. In fishes, these are chilomicrons, in arthropods, a lighter HDL (RYAN; VAN DER HORST, 2000). It only left to know how exogenous phospholipids favors this endogenous assembly of lipoproteic transporters: do they enter integrally, or in parts to rebuild the material inside? After that one will know also, the reason why some kind o phosphatidilcholine are better for digestion than others, and why phosphatidiletanolamine does not work? An explanation is expected at the level of apolipoprotein releasing control from endoplasmic reticulum, in which regarding to Apo-B under the best conditions, more than half of the newly-synthesized product is destroyed (ELLGAARD et al.,1999).

PUFA requirement on shrimp fattening

Fattening of juveniles ("post-larva") is the most frequent activity in aquaculture institutions or companies and, for this reason, the majority of the scientific articles on shrimp nutrition in specialized journals aims only this approach to evaluate quality of a feed ingredient and/or its components. Nevertheless, it is worth reminding that the easy measurement of weight gain differs a lot in complexity from this biometric data in arthropods. The gain in body mass in crustaceans means not only a tissue growth – in a mew cuticle – but also a given number of molts during the chosen interval for evaluation. Each molt makes the animal very susceptible to infections, to cannibalism on the vivarium and to other problems that not even involve digestion and feed metabolism aspects (CHENG et al., 2003). Tables detailing survival of tested animals – not always presented on publications – illustrate these problems.

A lot of technical obstacles remain on quantitative studies on essential lipids. The universal issue in nutrition experiences is to find means to allow evaluating the effect of a single ingredient, without creating unnatural conditions. Regarding to PUFA, it is known, for instance, that free fatty acids are detergent and in habitual feed they appear incorporated in polar lipids and triglycerides. Mixture of vegetal oil used in researches and commercial rations are not very alike to the fat in the diet of a wild crustacean, even that – for aquaculture fortune – the shrimp digestive system does not seem to distinguish them (DEERING et al., 1996). However, methyl esters used in some of the former researches on essential fatty acids are definitely unadvisable, once they can not be used as other sources of PUFA (GLENCROSS; SMITH, 1997). Finally, in researches on fat there are limitations inherent to the necessity of adding phospholipids to the experimental ration, because crustaceans perish fast without this ingredient (COUTTEAU et al., 1996, 1997; GONZÁLEZ-FÉLIX et al., 2002b). Polar lipids inevitably contain given amount of essential fatty acids that influence results on true requirements.

With these difficulties, not surprisingly solid divergences are observed among obtained results by different researchers. In a pioneer research, Shewbart and Mies (1973) added progressively more linolenic acid (ALA) to a *P. aztecus* standardized ration and cocluded that the ideal rate should lay between 1 and 2% of the dry weight. In a similar study performed with *P. indicus*, Read (1981) stimated a ideal concentration of ALA in 2%. Besides that, Kanazawa et al. (1979e) favored ALA 1% for *P. japonicus* even though their data suggest higher concentrations. Ren et al. (1994) published requirements of 1.95%, 1,09%, 0.20% and 0.37% for LOA, ALA, EPA and DHA, respectively, in *P. chinensis*. Lately, Xu et al. (1994a) mentioned a value lower than 1% for ALA, in the same specie. In Merican and Shim (1997) study with *P. monodon*, stable values of animal growth and survival (50 to 100 mg in the beginning of the assays) were reached only with 2.5% of ALA and 1,5% of DHA. On the other extreme, D'Abramo and Sheen (1993) asserted that for *M. rosenbergii*, only 0,075% of C≥20 PUFA were enough and even replacing DHA by ARA was not critical for the referred species. Anyway, it is necessary to observe that recent researches of GLENCROSS group in Australia already discussed do not cast forth isolated values for each essential fatty acid, but do work with a model that describes mathematically and convincingly how the animal can replace, until certain level, a given compound by another (GLENCROSS et al., 2002 a,b,c).

Since the PUFA 18:3n-3 (ALA) and 18:2n-6 (LOA) are essential and can not be interconverted, it was interesting to observe that the majority of marine crustaceans seem to prefer 18:3n-3 (GUARY et al., 1976; KANAZAWA et al., 1977b, 1979c; READ, 1981). In vertebrates and humans this does not happen. However, it seems that in *P. indicus* (READ, 1981) and in *M. rosenbergii* (REIGH; STICKNEY, 1989) the preference could really be for 18:2n-6, at least when LOA is accompanied by ALA (D'ABRAMO; SHEEN, 1993). Fenucci et al. (1981) recommended a quotient between PUFA n-3 and 18:2n-6 of 1.00 to 1.18 in order to reach better results with *P. stylirostris*. In article from REN et al (1994) one can find an interesting observation that in *P. chinensis*, LOA stimulated weight gain, whilst ALA favored growth in size and feed conversion. However, confusion over the most appropriate relationship between n-3 and n-6 may have a quite simple explanation, independent on the studied species. Montaño and Navarro (1996) observed wild species of *L. vannamei* with n-3/n-6 quotients altered and evidenciated that this phenomenon occurred less due to a large geographic distance among collection places than due to a season effect, colder in June than in December at the Pacific Ocean of the Equator. Next, they reminded that exist indeed other results, as in shrimp (*Palaemon serratus*) as in fishes (*Sciaenops ocellatus*) that support the PUFA n-6 prevalence hypothesis, and particularly, the one that LOA (18:2n-6) are related to warmer environmental temperatures and that of series n-3, colder (MARTIN; CECCALDI, 1977; BOTTINO et al., 1980; CRAIG et al., 1995). The above-mentioned conclusion solves also some doubts on the relevance of arachdonic acid 20:4n-6 (ARA) in crustaceans. In opposition to EPA, 20:5n-3, and to DHA, 22:6n-3, mentioned in almost every article on PUFA in shrimps, ARA appears only occasionally, completely on the contrary to the references on eicosanoids in humans. In our list of 36 references on PUFA in crustaceans, only 7 of those mention ARA (LILLY; BOTTINO, 1981; CHANMUGAM et al., 1983; DALL et al., 1992; D'ABRAMO; SHEEN, 1993; XU et al., 1993, 1994; GLENCROSS; SMITH, 2001). Lilly and Bottino (1981) found ARA in *P. setiferus*, however, the demonstration that ARA can not be synthesized by the cited shrimp, does not mean necessarily that it is also essential. In *P. esculentus*, Dall et al. (1992) could prove that ARA is dispensable. In their comparative studies, Xu et al. (1993; 1994a,b) place ARA nutritive value in *P. chinensis* between ALA and DHA. Chemical analysis performed in *M. rosenbergii* by D'Abramo and Sheen (1993) proved ARA presence in this species, but incorporations assays indicate a more important role of EPA and DHA. D'Abramo and Sheen (1993) mention the hypothesis previously casted by Chanmugam et al. (1983) that ARA presence could be related with *M. rosenbergii* habitat in fresh water, in contrast to the majority of cultivated species nowadays, which are marine. Finally, Glencross and Smith (2001) did not find any benefit in adding ARA to *P. monodon* feeding, since none of the other PUFA is lacking and admit the idea that ARA is not a essential fatty acid, at least in that species.

CONCLUSIONS

Although lipids form the most important energy reserve in animals, they can not surpass a relatively small fraction of shrimp nutrition, which is mainly supplied by proteic catabolism.

It is of greater importance the correct composition of ingested lipids, considering its essential components that animal can not synthesize.

PUFA form the main contingent of essential lipids. In nature, PUFA attain in animals higher concentrations than in captivity, considering EPA (20:5n-3) and DHA (22:6n-3) in particular. PUFA high rates grant increased survival, better resistance and fast growth, for reasons not yet understood. Zootechnical index mentioned get emphasized during larvae stage.

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This text is dedicated to the memory of Professor Kurt Georg Rehn.

REFERENCES

ARAUJO, M.; LAWRENCE, A. Fatty acid profile of muscle and midgut gland from wild *Penaeus californiensis*, *P. occidentalis*, *P. setiferus* and *P. vannamei*. **Journal World Aquaculture**, v.24, n.3. p.425-428, 1993.

ARCOS, F.G.; IBARRA, A.M.; PALACIOS, E.; VAZQUEZ-BOUCARD, C.; RACOTTA, I.S. Feasible predictive criteria for reproductive performance of white shrimp *Litopenaeus vannamei*: egg quality and female physiological condition. **Aquaculture**, Amsterdam, v.228, p.335-349, 2003.

BARBOSA LIMA, R.; FIGUEIREDO-LIMA, D.F. Critical review: cholesterol and fat-soluble vitamins on shrimp feeding. **Scientia Agraria Paranaensis**, Marechal Cândido Rondon Rondon. (In press).

BERGER, J.; MOLLER, D.E. The mechanisms of action of PPARs. **Annual Review of Medicine**, v.53, p.409-435, 2002.

BOTTINO, R.N.; GENNITY, J.; LILLY, ML.; SIMMONS, E.; FINNE, G. Seasonal and nutritional effects on the fatty acids of three species of shrimp, *P. setiferus*, *P. aztecus* e *P. duorarum*. **Aquaculture**, Amsterdam, v.19, p.139-148, 1980.

CASTELL, J.D.; LEE, D.J.; SINNHUBER, R.O. Essential fatty acids in the diet of rainbow trout (*Salrno gairdneri*): lipid metabolism and fatty acid composition. **Journal of Nutrition**, Bethesda, v.102, p.93-100, 1972.

CATACUTAN, M.R. Growth and fatty acid composition of *Penaeus monodon* juveniles fed various lipids. **Israeli Journal of Aquaculture - Bamidgeh**, Nir David, v.43, p.47-56, 1991.

CAVALLI, R.O.; TAMTINB, M.; LAVENSA, P.; SORGELOOSA, P. Variations in lipid classes and fatty acid content in tissues of wild *Macrobrachium rosenbergii* (de Man) females during maturation. **Aquaculture**, Amsterdam, v.193, p.311-324, 2001.

CHANMUGAM, P.; DONOVAN, J.; WHEELER, C.J.; HWANG, D.H. Differences in the lipid composition of freshwater prawn (*Macrobrachium rosenbergii*) and marine shrimp. **Journal of Food Science**, Amsterdam, v.48, p.1440-1443, 1983.

CHENG, W.; JUANGB, F.M.; LIA, J.T.; LINA, M.C.; LIUC, C.H.; CHEN, J.C. The immune response of the giant freshwater prawn *Macrobrachium rosenbergii* and its susceptibility to *Lactococcus garvieae* in relation to the moult stage. **Aquaculture**, Amsterdam, v.218, p.33-45, 2003.

COLVIN, P.M. The effect of selected seed oils in the fatty acid composition and growth of *Penaeus indicus*. **Aquaculture**, Amsterdam, v.8, p.80-89, 1976.

CONKLIN, D.E.; D'ABRAMO, L.R.; BORDNER, C.E.; BAUM, N.A. A successful purified diet for the culture of juvenile lobsters: the effect of lecithin. **Aquaculture**, Amsterdam, v.21, p.243-249, 1980.

COUTTEAU, P.; CAMARA, M.R.; SORGELOOS, P. The effect of different levels and sources of dietary phosphatidylcholine on the growth, survival, stress resistance, and fatty acid composition of postlarval *Penaeus vannamei*. **Aquaculture**, Amsterdam, v.147, p.261-273, 1996.

COUTTEAU, P.; GEURDEN, I.; CAMARA, M.R.; BERGOT, P.; SORGELOOS, P. Review on the dietary effects of phospholipids in fish and crustacean larviculture. **Aquaculture**, Amsterdam, v.155, p.149-164, 1997.

CRAIG, S.R.; NEIL, W.H.; GATLIN, D.M. Effects of dietary lipid and environmental salinity on growth, body composition, and cold tolerance of juvenile red drum (*Sciaenops ocellatus*). **Fish Physiology and Biochemistry**, v.14, p.49-61, 1995.

D'ABRAMO, L.R.; BORDNER, C.E.; CONKLIN, D.E.; BAUM, N.A. Essentiality of dietary phosphatidylcholine for the survival of juvenile lobsters. **Journal of Nutrition**, Bethesda, v.111, p.425-431, 1981.

D'ABRAMO, L.R.; BAUM, N.A.; BORDNER, C.E.; CONKLIN, D.E.; CHANG, E.S. Diet-dependent cholesterol transport in the American lobster. **Journal of Experimental Marine Biology and Ecology**, Amsterdam, v.87, p.83-96, 1985.

D'ABRAMO, L.R.; BORDNER, C.E.; CONKLIN, D.E. Relationship between dietary phosphatidylcholine and serum cholesterol in the lobster *Homarus* sp. **Marine Biology**, Heidelberg, v.67, p.231-235, 1982.

D'ABRAMO, L.R.; SHEEN, S.S. Polyunsaturated fatty acid nutrition in juvenile freshwater prawn *Macrobrachium rosenbergii*. **Aquaculture**, Amsterdam, v.115, p.63-86, 1993.

DALL, W.; CHANDUMPAI, A.; SMITH, D.M. Fatty acid composition of organs and tissues of the tiger prawn *Penaeus esculentus* during the moulting cycle and during starvation. **Marine Biology**, Heidelberg, v.113, p.45-55,1992.

DEERING, M.J.; FIELDER, D.R.; HEWITT, D.R. Growth and fatty acid composition of juvenile leader prawns, *Penaeus monodon*, fed different lipids. **Aquaculture**, Amsterdam, v.151, p.131-141, 1997.

DURICA, D.S.; HOPKINS, P.M. Expression of the genes encoding the ecdysteroid and retinoid receptors in the regenerating limb tissues from the fiddler crab, *Uca pugilator*. **Gene**, Amsterdam, v.171, p.237-241, 1996.

DURICA, D.S.; CHUNG, A.C.; HOPKINS, P.M. Characterization of EcR and RXR gene homologs and receptor expression during the molt cycle in the crab, *Uca pugilator*. **American Zoologist**, Seattle, v.39, p.758-773, 1999.

ELLGAARD, L.; MOLINARI, M.; HELENIUS, A. Setting the standards: quality control in the secretory pathway. **Science**, Washington, v.286, p.1882-1888, 1999.

FISHERIES AND AQUACULTURE DEPARTMENT - FAO. 2013. **Global aquaculture production statistics for the year 2011** [online]. Available at: <http://cape-eaprac.co.za/projects/NMM101%20Marine%20Aquaculture/DEIR/Appendix%20F%20GlobalAquacultureProductionStatistics2011.pdf>. Last accessed: 12 apr. 2016.

FENUCCI, J.L.; LAWRENCE, A.L.; ZEIN-ELDIN, Z.P. The effects of fatty acid and shrimp meal composition of prepared diets on growth of juvenile shrimp, *Penaeus stylirostris*. **Journal of the World Mariculture Society**, Baton Rouge, v.12, p.315-324, 1981.

GLENCROSS, B.D.; SMITHB, D.M.; THOMASB, M.R.; WILLIAMSB, K.C. Optimising the essential fatty acids in the diet for weight gain of the prawn, *Penaeus monodon*. **Aquaculture**, Amsterdam, v.204, p.85-99, 2002a.

GLENCROSS, B.D.; SMITH, D.M.; THOMAS, M.R.; WILLIAMS, K.C. The effect of dietary n-3 and n-6 fatty acid balance on the growth of the prawn *Penaeus monodon*. **Aquaculture Nutrition**, Oxford, v.8, p.43-51, 2002b.

GLENCROSS, B.D.; SMITH, D.M.; THOMAS, M.R.; WILLIAMS, K.C. The effects of dietary lipid amount and fatty-acid composition on the digestibility of lipids by the prawn, *Penaeus monodon*. **Aquaculture**, Amsterdam, v.205, p.157-169, 2002c.

GLENCROSS, B.D.; SMITH, D.M. Comparison of triacylglycerols, esterified and free fatty acids as neutral lipid sources in the diet of the prawn *Penaeus monodon*. **Aquaculture**, Amsterdam, v.159, p.67-85, 1997.

GLENCROSS, B.D.; SMITH, D.M. A study of the arachidonic acid requirements of the giant tiger prawn, *Penaeus monodon*. **Aquaculture Nutrition**, Oxford, v.8, p.59-69, 2001.

GONZÁLEZ-FÉLIX, M.L.; GATLIN, D.M.; LAWRENCEA, A.L.; PEREZ-VELAZQUEZA, M. Effect of dietary phospholipid on essential fatty acid requirements and tissue lipid composition of *Litopenaeus vannamei* juveniles. **Aquaculture**, Amsterdam, v.207, p.151-167, 2002.

GONZÁLEZ-FÉLIX, M.L.; LAWRENCE, A.L.; GATLIN, D.M.; PEREZ-VELAZQUEZ, M. Nutritional evaluation of fatty acids for the open thelycum shrimp, *Litopenaeus vannamei*: I. Effect of dietary linoleic and linolenic acids at different concentrations and ratios on juvenile shrimp growth, survival and fatty acid composition. **Aquaculture Nutrition**, Oxford, v.9, p.105-113, 2003a.

GONZÁLEZ-FÉLIX, M.L.; GATLIN, D.M.; LAWRENCE, A.L.; PEREZ-VELAZQUEZ, M. Nutritional evaluation of fatty acids for the open thelycum shrimp, *Litopenaeus vannamei*: II. Effect of dietary n-3 and n-6 polyunsaturated and highly unsaturated fatty acids on juvenile shrimp growth, survival, and fatty acid composition. **Aquaculture Nutrition**, Oxford, v.9,115-122, 2003b.

GUARY, J.C.; KAYAMA, M.; MURAKAMI, Y.; CECCALDI, H.J. The effects of a fat-free diet and compounded diets supplemented with various oils on molt, growth and fatty acid composition of prawn, *Penaeus japonicus* Bate. **Aquaculture**, Amsterdam, v.7, p.245-254, 1976.

HADAS, E.; KOVENA, W.; SKLANB, D.; TANDLERA, A. The effect of dietary phosphatidylcholine on the assimilation and distribution of ingested free oleic acid (18:1n-9) in gilthead seabream (*Sparus aurata*) larvae. **Aquaculture**, Amsterdam, v.17 p.577-588, 2003.

KANAZAWA, A.; TESHIMA, S.; TOKIWA, S. Nutritional requirements of prawn. VII. Effect of dietary lipids on growth. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.43, 849-856, 1977a.

KANAZAWA, A.; TESHIMA, S.; TOKIWA, S.; CECCALDI, H.J. Essential fatty acids in the diet of prawn. I. Effects of linoleic and linolenic acids on growth. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.43, p.1111-1114, 1977b.

KANAZAWA, A.; TESHIMA, S.; ENDO, M.; KAYAMA, M. Effects of eicosapentaenoic acid on growth and fatty acid composition of the prawn, *Penaeus japonicus*. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.27, p.35-40, 1978.

KANAZAWA, A.; TESHIMA, S.; TOKIWA, S. Biosynthesis of fatty acids from palmitic acid in the prawn, *Penaeus japonicus*. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.28, p.17-20, 1979a.

KANAZAWA, A.; TESHIMA, S.; ONO, K. Relationship between essential fatty acid requirements of aquatic animals and the capacity for bioconversion of linolenic acid to highly unsaturated fatty acids. **Comparative Biochemistry and Physiology B**, Amsterdam, v.63B, p.295-298, 1979b.

KANAZAWA, A.; TESHIMA, S.; TOKIWA, S.; CECCALDI, H. Effects of dietary linoleic and linolenic acids on growth of prawn. **Oceanologica Acta**, Les Ulis, v.2, p.41-47, l979c.

KANAZAWA, A.; TESHIMA, S.; ONO, K.; CHALAYONDEJA, K. Biosynthesis of fatty acids from acetate in prawns Penaeus monodon and *Penaeus merguiensis*. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.28; p.21-26. 1979d.

KANAZAWA, A.; TESHIMA, S.; ENDO, M. Requirements of prawn, Penaeus japonicus, for essential fatty acid. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.28, p.27-33, 1979e.

KANAZAWA, A.; TESHIMA, S.; TOKIWA, S.; ENDO, M.; ABDEL RAZEK, A. Effects of short-necked clam phospholipids on the growth of prawn. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.45, p.961-965, 1979f.

KANAZAWA, A.; TESHIMA, S-I.; TOKIWA, S.; HIRATA, M. Essential fatty acids in the diet of prawn. II. Effect of docosahexaenoic acid on growth. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.45, p.1151-1153, 1979g.

KANAZAWA, A.; TESHIMA, S-I.; SAKAMOTO, M. Effects of dietary lipids, fatty acids, and phospholipids on growth and survival of prawn (*Penaeus japonicus*) larvae. **Aquaculture**, Amsterdam, v.50, p.39-49, 1985a.

KANAZAWA, A. et al. Effects of dietary bonito-egg phospholipids and some phospholipids on growth and survival of the larval ayu, *Plecoglossus altivelis*. **Zeitschrift für Angewandte Ichthyologie/Journal of Applied Ichthyology**, Hamburg, v.4, p.165-170, 1985b.

KANAZAWA, A.; TESHIMA, S. Biosynthesis of fatty acids from acetate in the prawn, *Penaeus japonicus*. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.26, p.49-53, 1977.

KAYAMA, M. et al. Essential fatty acids in the diet of prawn Ill Lipid metabolism and fatty acid composition. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, v.46, p.483-488, 1980.

KONTARA, E.K.M.; COUTTEAU, P.; SORGELOOS, P. Effect of dietary phospholipid on requirements for and incorporation of n-3 highly unsaturated fatty acids in postlarval *Penaeus japonicus* Bate. **Aquaculture**, Amsterdam, v.158, p.305-320, 1997.

LILLY, M.L.; BOTTINO, N.R. Identification of arachidonic acid in Gulf of Mexico shrimp and degree of biosynthesis in *Penaeus setiferus*. **Lipids**, Champaign, v.16, p.871-875, 1981.

LIM, C.; AKO, H.; BROWN, C.L.; HAHN, K. Growth response and fatty acid composition of juvenile *Penaeus vannamei* fed different sources of dietary lipid. **Aquaculture**, Amsterdam, v.151, p.143-153, 1997.

MANGELSDORF, D.J.; EVANS, R.M. The heterodimers and orphan receptors. **Cell**, Cambridge, v.10, p.940-954, 1995.

MARTIN, B.J. Croissance et acides gras de la crevette *Palaemon serratus* (Crustacea, Decapoda) nourrie avec des aliments composes contenant differentes taux d'acide linoleique et linolenique. **Aquaculture**, Amsterdam, v.19, p.325-337, 1980.

MARTIN, B.J.; CECCALDI, H.J. Influence de la temperature sur la composition en acides gras du muscle abdominal de *Palaemon serratus*. **Biochemistry and Systematic Ecology**, v.5, p.151-154, 1977.

MERICAN, Z.O.; SHIM, K.F. Qualitative requirements of essential fatty acids for juvenile *Penaeus monodon*. **Aquaculture**, Amsterdam, v.147, p.275-291, 1996.

MERICAN, Z.O.; SHIM, K.F. Quantitative requirements of linolenic and docosohexaenoic acid for juvenile *Penaeus monodon*. **Aquaculture**, Amsterdam, v.157, p.277-295, 1997.

MIDDLEDITCH, B.S.; MISSLER, S.R.; HINES, H.B.; MCVEY, J.P.; BROWN, A.; WARD, D.G.; LAWRENCE, A.L. profiles of penaeid shrimp: Dietary lipids and ovarian maturation. **Journal of Chromatography**, Amsterdam, v.195, p.359-368, 1980.

MILLAMENA, O.M. Effect of fatty acid composition of broodstock diet on tissue fatty acid patterns and egg fertilization and hatching in pond-reared *Penaeus monodon*. **Asian Fisheries Science**, Quezon City, v.2, p.127-134, 1989.

MONTAÑO, M.; NAVARRO, J.C. Fatty acids of wild and cultured *Penaeus vannamei* larvae from Ecuador. **Aquaculture**, Amsterdam, v.142, p.259-268, 1996.

O'LEARY, C.D.; MATTHEWS, A.D. Lipid class distribution and fatty acid composition of wild and farmed prawn, *Penaeus monodon* (Fabricius). **Aquaculture**, Amsterdam, v.89, p.65-81, 1990.

PAHLOW, M.; VAN OEL, P.R.; MEKONNEN, M.M.; HOEKSTRA, A.Y. Increasing pressure on freshwater resources due to terrestrial feed ingredients for aquaculture production. **Science of the Total Environment**, v.536, p. 847-857, 2015.

PETRIELLA, A.M.; MULLER, M.I.; FENUCCI, J.L.; SAEZ, M.B. Influence of dietary fatty acids and cholesterol on the growth and survival of the Argentine prawn, *Artemesia longinaris* Bate. **Aquaculture**, Amsterdam, v.37, p.11-20, 1984.

READ, G.H.L. The response of *Penaeus indicus* (Crustacea: Penaeidae) to purified and compounded diets of varying fatty acid composition. **Aquaculture**, Amsterdam, v.24, p.245-256, 1981.

REIGH, R.C.; STICKNEY, R.R. Effects of purified fatty acids on the fatty acid composition of freshwater shrimp, *Macrobrachium rosenbergii*. **Aquaculture**, Amsterdam, v.77, p.157-174. 1989.

REN, Z.; LI, A.; XUE, C. Nutrient requirements of *Penaeus chinensis* for essential fatty acids. **Journal of the Ocean University Qingdao/Qingdao Haiyang Daxue Xuebao**, Qingdao, v.24, p.24-32, 1994.

RYAN, R.O.; VAN DER HORST, D.J. Lipid transport biochemistry and its role in energy production. **Annual Review of Entomology**, Palo Alto, v.45, p.233-260, 2000.

SANDIFER, P.A.; JOSEPH, J.D. Growth responses and fatty acid composition of juvenile prawns (*Macrobrachium rosenbergii*) fed a prepared ration augmented with shrimp head oil. **Aquaculture**, Amsterdam, v.8, p.129-138, 1976.

SHEWBART, K.L.; MIES, W.L. Studies on nutritional requirements of brown shrimp - the effect of linolenic acid on growth of *Penaeus aztecus*. **Proceedings of the World Mariculture Society**, Baton Rouge, v.4, p.263-276, 1973.

SHIAU, S-Y. Nutrient requirements of penaeid shrimps. **Aquaculture**, Amsterdam, v.164, p.77-93, 1998.

SINGER, S.J.; NICOLSON, G.L. The fluid mosaic model of the structure of cell membranes. **Science**, Washington, v.175, p.720-731, 1972.

STEINMETZ, A.C.U.; RENAUD, J.P.; MORAS, D. Binding of ligands and activation of transcription by nuclear receptors. **Annual Review of Biophysics and Biomolecular Structure**, Palo Alto, v.30, p.329-359, 2001.

TESHIMA, S.; KANAZAWA, A.; SASADA, H.; KAWASAKI, M. Requirements of larval prawn, *Penaeus japonicus* for cholesterol and soybean phospholipids. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.31, p.193-199, 1982.

TESHIMA, S; KANAZAWA, A.; KAKUTA, Y. Effects of dietary phospholipids on growth and body composition of the juvenile prawn. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.52, p.155-158, 1986a.

TESHIMA, S.; KANAZAWA, A.; KAKUTA, Y. Effects of dietary phospholipids on lipid transport in the juvenile prawn. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.52, p.159-163, 1986b.

TESHIMA, S.; KANAZAWA, A.; KAKUTA, Y. Role of dietary phospholipids in the transport of ^{14}C tripalmitin in the prawn. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.52, p.519-524, 1986c.

TESHIMA, S.; KANAZAWA, A.; KAKUTA, Y. Role of dietary phospholipids in the transport of ^{14}C cholesterol in the prawn. **Bulletin of the Japanese Society of Scientific Fisheries/Nippon Suisan Gakkaishi**, Tokyo, v.52, p.719-723, 1986d.

TESHIMA, S.; KANAZAWA, A.; KAKUTA, Y. Growth, survival and body lipid composition of the prawn larvae receiving several dietary phospholipids. **Memoirs of Faculty of Fisheries Kagoshima University**, Kagoshima, v.35, p.17-27, 1986e.

WEI, L.N. Retinoid receptors and their coregulators. **Annual Review of Pharmacology and Toxicology**, Palo Alto, v.43, p.47-72, 2003.

WOUTERS, R.; MOLINAA, C.; LAVENSB, P.; CALDERÓNA, J. Lipid composition and vitamin content of wild female *Litopenaeus vannamei* in different stages of sexual maturation. **Aquaculture**, Amsterdam, v.198, p.307-323, 2001a.

XU, X.; JI, W.; CASTELL, J.D.; O'DOR, R. The nutritional value of dietary n-3 and n-6 fatty acids for the Chinese prawn (*Penaeus chinensis*). **Aquaculture**, Amsterdam, v.118, p.277-285, 1993.

XU, X.L.; Ji, W.J.; CASTELL, J.D.; O'DOR, R.K. Influence of dietary lipid sources on fecundity, egg hatchability and fatty acid composition of Chinese prawn (*Penaeus chinensis*) broodstock. **Aquaculture**, Amsterdam, v.119, p.359-370, 1994a.

XU, X.L.; Ji, W.J.; CASTELL, J.D.; O'DOR, R.K. Essential fatty acid requirement of the Chinese prawn, *Penaeus chinensis*. **Aquaculture**, Amsterdam, v.127, p.29-40, 1994b.