WEP Warwick Evans Publishing

International Journal of Public Health and Medical Research

ISSN: 3006-7707 (Print), ISSN: 3006-3752 (Online) | Volume 6, Number 4, Year 2026
DOI: https://doi.org/10.62051/ijphmr.v6n4.09
Journal homepage: https://wepub.org/index.php/IJPHMR/index

Triangular Lipid Strategy for Neurodevelopment: Formulation Engineering, Nanocarrier Performance, and Evidence Base of a BCLC Acer truncatum Seed Oil-Phosphatidylserine-Linseed Oil Composite

Nour-Eddine Ziraoui *, Tomás Valverde, Nathaniel Prescott

National Standards Laboratory SA, Chemin des Orlons 10 CH-1860 Aigle, Switzerland
*Corresponding Author: info@ns-lab.ch

ABSTRACT

We integrated formulation-characterization data, process-optimization records, nanocarrier-performance testing, storage-stability observations, and peer-reviewed literature to evaluate a BCLC lipid composite built around Acer truncatum seed oil, phosphatidylserine (PS), and linseed oil. The formulation dataset showed that the most favorable preparation window was obtained at an oil-phase temperature of 45 C, aqueous-phase pH 7.4, 4 min of high-speed shearing, and four high-pressure homogenization cycles. Under these conditions, the hybrid nanocarrier exhibited an average particle size of about 148 nm, a polydispersity index of 0.14, a zeta potential of -35 mV, encapsulation efficiencies of 93% for Acer truncatum seed oil, 91% for PS, and 92% for DHA phospholipid, and limited particle-size changes in simulated gastric and intestinal fluids (5% and 7%, respectively). During 28 days of storage, low-temperature light-protected conditions produced the slowest rise in peroxide and acid values. Published evidence aligned with this formulation logic: nervonic acid has been linked to myelin biology, Acer truncatum seed oil has shown cognition-related benefits in rodent models, PS supports membrane signaling and has demonstrated clinical signals in pediatric cognition studies, and omega-3 fatty-acid sufficiency remains relevant to neurodevelopmental outcomes. Taken together, the current data support a triangular lipid strategy in which myelin-oriented lipids, membrane phospholipids, and omega-lipid carrier support are organized within a phospholipid-assisted nanocarrier.

KEYWORDS

Acer truncatum seed oil; Nervonic acid; Phosphatidylserine; Linseed oil; Neurodevelopment; Nanocarrier; Lipid nutrition

1. INTRODUCTION

Neurodevelopment depends on a coordinated supply of structural lipids, membrane phospholipids, and oxidation-resistant carrier systems. When nutrient design addresses only a single axis, such as one fatty acid or one phospholipid class, it often fails to capture the multiple demands of neural membrane assembly, myelination, signaling, and post-absorptive stability. In the present work, we evaluate a BCLC composite centered on Acer truncatum seed oil, phosphatidylserine (PS), and linseed oil and examine whether this triad can be understood as a coherent neurodevelopment-oriented lipid strategy.

The formulation architecture combines three front-end modules. Acer truncatum seed oil provides a nervonic-acid-rich botanical lipid fraction; PS contributes neuronal membrane structure and signaling relevance; and linseed oil broadens the membrane-phase lipid environment and carrier continuity.

Content from this work may be used under the terms of CC BY-NC 4.0 licence (https://creativecommons.org/licenses/by-nc/4.0/). Published by Warwick Evans Publishing.

These three modules are supported by auxiliary phospholipids, sialic acid, phytosterol, tocopherol protection, and a controlled hybrid nanocarrier process. Rather than evaluating the system as a simple ingredient blend, we considered both its internal formulation-performance profile and the extent to which published neurodevelopment and membrane-biology evidence supports its rationale.

2. MATERIALS AND METHODS

We organized the technical-development record of the BCLC composite into a conventional manuscript structure and complemented it with peer-reviewed literature indexed through March 2026. The literature review focused on Acer truncatum seed oil, nervonic acid, phosphatidylserine, alpha-linolenic acid, omega-3 fatty acids, phospholipid nanocarriers, cognition, myelination, and neurodevelopment. We prioritized review articles, randomized trials, and mechanistic studies directly relevant to myelin biology, membrane function, or developmental neurocognition.

The formulation record described a lipid-phospholipid hybrid nanocarrier containing 8-12 parts Acer truncatum seed oil, 3-6 parts PS, 1-2 parts cephalin, 2-4 parts linseed oil, 0.5-2 parts arachidonic acid phosphatidylinositol, 1-3 parts DHA phospholipid, 0.3-1.5 parts sialic acid, 0.2-1 part phytosterol, 0.1-0.8 part d-alpha-tocopherol, 0.5-2 parts co-emulsifier, and 0.05-0.3 part antioxidant synergist. Raw-material characterization included cold-pressed Acer truncatum seed oil with nervonic acid 6.1%, unsaturated fatty acids 89%, peroxide value 2.3 mmol/kg, and acid value 0.6 mg KOH/g; soy-derived PS with 68% effective purity; and cephalin with 58% effective purity.

The process-optimization dataset examined four variables: oil-phase temperature, aqueous-phase pH, high-speed shearing time, and number of high-pressure homogenization cycles. Outcome variables were average particle size, polydispersity index (PDI), zeta potential, encapsulation efficiency, simulated digestive-fluid stability, and 28-day storage peroxide and acid values under three storage conditions.

Table 1. Signature triad and formulation logic

Signature active	Primary neurodevelopment role	Technical specification	Formulation implication
Acer truncatum seed oil	Myelin-oriented lipid support	Cold-pressed at 43 C; nervonic acid 6.1%; unsaturated fatty acids 89%	Provides the signature neuro-lipid identity and the main core-loading oil phase
Phosphatidylserine	Neuronal membrane architecture and signaling support	Soy-derived; effective purity 68%; also used as surface-modification phospholipid	Functions as both an active phospholipid and a carrier-structuring component
Linseed oil	Omega-lipid carrier continuity	2-4 parts in the formulation; used as base membrane material	Expands the lipid matrix and supports continuity of the hybrid carrier phase

Table 2. Representative raw-material characterization

Raw material	Key quality indicators
Acer truncatum seed oil	43 C pressing; nervonic acid 6.1%; peroxide value 2.3 mmol/kg; acid value 0.6 mg KOH/g
Phosphatidylserine	68% effective purity; free fatty acid 0.7%; moisture 0.3%
Cephalin	58% effective purity; phosphatidylethanolamine 92%; acid value 1.7 mg KOH/g
Arachidonic acid phosphatidylinositol	97% purity; head-group retention 98.8%; arachidonic-acid binding 94%
DHA phospholipid	DHA 46%; phosphatidylcholine 87%; oxidation value 1.7 mmol/kg

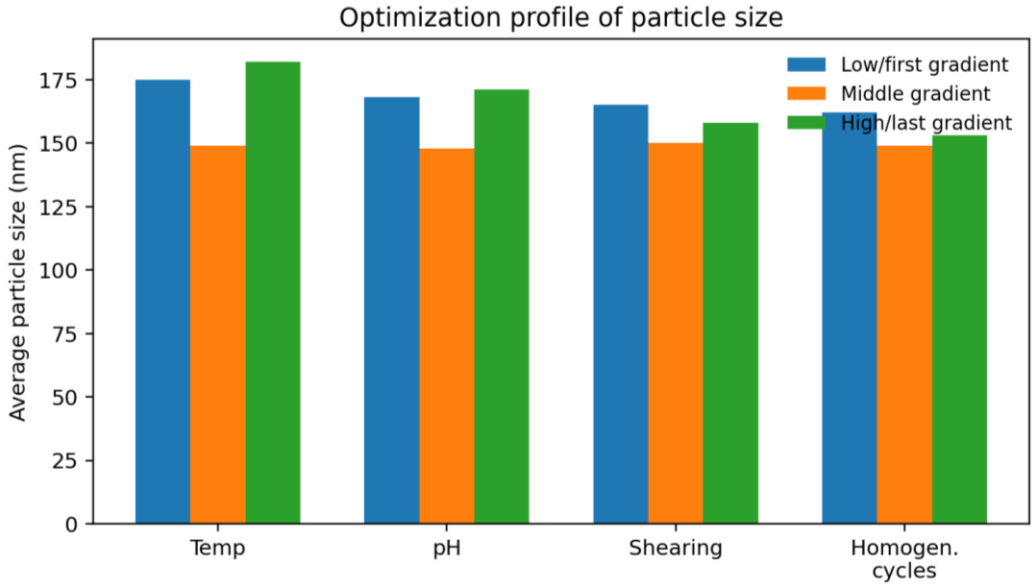

Figure 1. Optimization profile of particle size across the four key preparation variables

3. RESULTS

Across the optimization gradients, the middle operating window consistently performed best. The preferred preparation conditions were 45 C oil-phase temperature, pH 7.4 aqueous phase, 4 min of high-speed shearing, and four homogenization cycles. This configuration kept the particle-size profile within a narrow nanoscale range and avoided the broader dispersity observed at lower or higher settings in the same optimization series.

Under optimized conditions, the nanocarrier achieved a mean particle size of 148 nm, PDI of 0.14, and zeta potential of -35 mV. Encapsulation efficiency reached 93% for Acer truncatum seed oil, 91% for PS, and 92% for DHA phospholipid. The size-change rate remained limited after exposure to simulated digestive conditions, with 5% change in simulated gastric fluid at 2 h and 7% change in simulated intestinal fluid at 4 h. These results indicate good structural integrity during early gastrointestinal transit.

Table 3. Nanocarrier-performance summary under optimized conditions

Indicator	Result
Average particle size	148 nm
Polydispersity index (PDI)	0.14
Zeta potential	-35 mV
Encapsulation efficiency of Acer truncatum seed oil	93%
Encapsulation efficiency of phosphatidylserine	91%
Encapsulation efficiency of DHA phospholipid	92%
Particle-size change in simulated gastric fluid (2 h)	5%
Particle-size change in simulated intestinal fluid (4 h)	7%

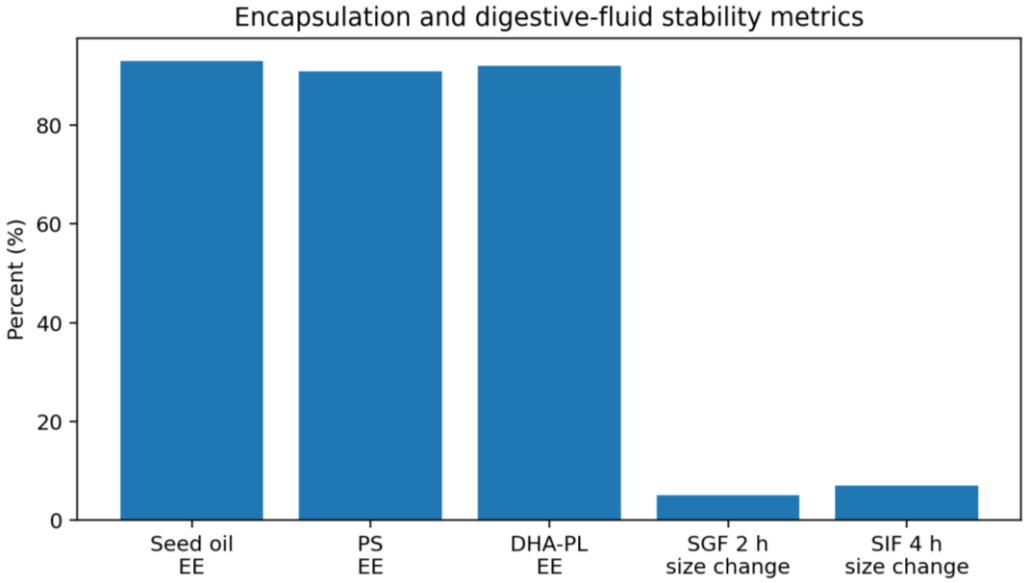

Figure 2. Encapsulation efficiencies of core lipid actives and particle-size stability in simulated digestive fluids

Storage testing over 28 days showed the slowest oxidative drift under low-temperature, light-protected conditions. At day 28, peroxide value was 2.0 mmol/kg and acid value was 0.6 mg KOH/g under low-temperature protection, compared with 2.5 and 0.8 under room temperature with light protection and 2.8 and 0.9 under room temperature with light exposure. This pattern supports the compatibility between the lipid triad and a protected processing/storage workflow.

Table 4. Day-28 storage-stability comparison

Storage condition	Time point	Peroxide value (mmol/kg)	Acid value (mg KOH/g)
Room temp, protected from light	28 days	2.5	0.8
Room temp, light exposure	28 days	2.8	0.9
Low temp, protected from light	28 days	2.0	0.6

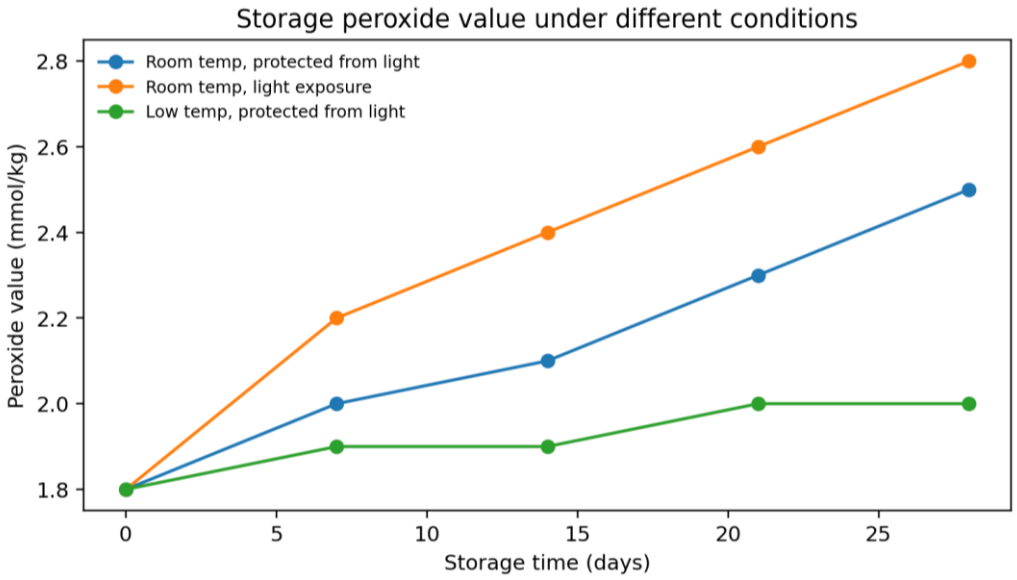

Figure 3. Peroxide-value trajectories under three storage conditions over 28 days

Published evidence reinforced the mechanistic logic of the formulation. Song et al. reported that Acer truncatum seed oil increased learning and memory performance in rats while regulating sphingolipid and glycerophospholipid pathways [1]. Lewkowicz et al. showed that a naturally occurring nervonic-acid ester improved myelin synthesis in human oligodendrocytes [2]. Chen et al. observed that Acer truncatum seed extract reduced neuronal edema and improved motor ability in a hypoxic-ischemic encephalopathy rat model [4]. In parallel, PS has been described as abundant in the brain and central to membrane signaling, neurotransmission, and synaptic refinement [5, 6]. In children with ADHD, PS supplementation improved ADHD symptoms and short-term auditory memory in a randomized placebo-controlled trial [7], whereas a more recent healthy-child trial found no overall effect in the full cohort but reported benefit on a visuospatial memory task in a predefined lower-performing subgroup, with good tolerability [8]. Omega-3 and related PUFA literature remains mixed overall, but both the classic developmental review by Innis and a recent systematic review indicate that lipid sufficiency is relevant to neural development and that some short-term benefits can be detected in attention, working memory, executive function, and communication domains [9, 10].

Table 5. Selected published evidence relevant to the present lipid triad

Published study	Model / population	Main finding	Relevance to current formulation
Song et al. 2022 [1]	Rats given Acer truncatum seed oil	Learning and memory increased; sphingolipid and glycerophospholipid pathways were regulated	Supports cognition-related and lipid-remodeling relevance of Acer truncatum seed oil
Lewkowicz et al. 2019 [2]	Human oligodendrocytes	Naturally occurring nervonic-acid ester improved myelin synthesis	Supports myelin-oriented rationale for nervonic-acid-rich lipid inputs
Destaillats et al. 2025 [3]	Narrative review on infant nutrition	Nervonic acid was described as fundamental to sphingolipid and myelin biology and present only in minute amounts in human milk	Supports developmental relevance of nervonic acid supply
Chen et al. 2023 [4]	Hypoxic-ischemic encephalopathy rat model	Acer truncatum seed extract reduced neuronal edema and improved motor ability	Supports neuroprotective plausibility in injury-related developmental settings
Hirayama et al. 2014 [7]	36 children with ADHD	200 mg/day PS for 2 months improved ADHD symptoms and short-term auditory memory	Supports clinical neurocognitive relevance of PS in pediatric populations
Friling et al. 2025 [8]	Healthy children aged 8-12 years	No overall effect in the total cohort; visuospatial-memory benefit in a predefined lower-performing subgroup; safe and well tolerated	Suggests PS effects may depend on baseline phenotype and outcome selection
Innis 2008 [9] and Sherzai et al. 2022 [10]	Developmental lipid reviews and systematic review	Omega-3 adequacy was linked to neural development, and some short-term benefits were observed for attention, working memory, executive function, and communication	Supports the broader membrane-lipid context for linseed-oil inclusion and developmental lipid sufficiency

4. DISCUSSION

Taken together, the current evidence supports interpreting the BCLC composite as a triangular lipid strategy rather than a single-ingredient supplement. Acer truncatum seed oil contributes a nervonic-acid-rich lipid identity linked to myelin-oriented biology; PS provides both structural and signaling relevance within neuronal membranes; and linseed oil broadens the omega-lipid environment and helps sustain a continuous carrier phase. The auxiliary phospholipid system and controlled nanocarrier design add a second level of differentiation by improving loading, colloidal uniformity, and resistance to early digestive destabilization.

The literature also helps explain why the formulation may matter beyond nominal ingredient inclusion. Nervonic acid is increasingly discussed as a component of myelin-related lipid biology and infant neurodevelopment [2, 3]. PS is not only a supplemental ingredient but also a membrane-active phospholipid with established relevance to neuronal signaling and synaptic organization [5, 6]. Plant-derived omega-lipid sufficiency, including alpha-linolenic-acid-rich inputs, remains relevant to developmental neurobiology because membrane lipid composition influences neurogenesis,

neurotransmission, and visual and cognitive function [9-11]. Moreover, phospholipids are recognized as versatile self-assembling excipients that can support nanoscale drug and nutrient delivery systems [12].

Our interpretation should remain bounded by the available evidence. The internal formulation dataset provides optimization, loading, digestive-fluid stability, and storage information, but it does not by itself establish clinical efficacy in infants or children. The published literature offers mechanistic and selected clinical support, yet the evidence base remains heterogeneous across populations, dosages, and outcome measures. For that reason, the most defensible conclusion is that the BCLC composite has a strong formulation-performance profile and a biologically plausible neurodevelopment rationale, and that it merits stepwise validation in in vivo developmental models and prospective clinical studies.

5. CONCLUSION

We conclude that the BCLC Acer truncatum seed oil-PS-linseed oil composite can be framed as a neurodevelopment-oriented lipid platform in which myelin support, membrane phospholipid function, and omega-lipid carrier continuity are integrated within a phospholipid-assisted nanocarrier. The optimized formulation showed favorable particle-size control, high encapsulation efficiency, acceptable digestive-fluid stability, and stronger oxidative robustness under protected storage. When these internal data are interpreted together with the published literature on nervonic acid, PS, and developmental lipid nutrition, the composite demonstrates a coherent evidence base for further translational evaluation.

REFERENCES

[1] Song W, Zhang K, Xue T, Han J, Peng F, Ding C, et al. Cognitive improvement effect of nervonic acid and essential fatty acids on rats ingesting Acer truncatum Bunge seed oil revealed by lipidomics approach. Food Funct. 2022; 13(5):2475-2490. doi:10.1039/d1fo03671h.

[2] Lewkowicz N, Piątek P, Namiecińska M, Domowicz M, Bonikowski R, Szemraj J, et al. Naturally occurring nervonic acid ester improves myelin synthesis by human oligodendrocytes. Cells. 2019; 8(8):786. doi:10.3390/cells8080786.

[3] Destaillats F, Oliveira M, Rakitsky W, Zhou X, Parker L. Nervonic acid in infant nutrition: a forward-looking approach to enhancing neurodevelopmental outcomes. Front Nutr. 2025; 12:1635266. doi:10.3389/fnut.2025.1635266.

[4] Chen X, Song Y, Song W, Han J, Cao H, Xu X, et al. Multi-omics reveal neuroprotection of Acer truncatum Bunge seed extract on hypoxic-ischemia encephalopathy rats under high-altitude. Commun Biol. 2023; 6:1001. doi:10.1038/s42003-023-05341-9.

[5] Kim HY, Huang BX, Spector AA. Phosphatidylserine in the brain: metabolism and function. Prog Lipid Res. 2014; 56:1-18. doi:10.1016/j.plipres.2014.06.002.

[6] Ma X, He C, Huang Y, Wang H, Zhou S, Chen Y, et al. Phosphatidylserine, inflammation, and central nervous system diseases. Front Aging Neurosci. 2022; 14:975176. doi:10.3389/fnagi.2022.975176.

[7] Hirayama S, Terasawa K, Rabeler R, Hirayama T, Inoue T, Tatsumi Y, et al. The effect of phosphatidylserine administration on memory and symptoms of attention-deficit hyperactivity disorder: a randomised, double-blind, placebo-controlled clinical trial. J Hum Nutr Diet. 2014; 27 Suppl 2:284-291. doi:10.1111/jhn.12090.

[8] Friling M, Jackson PA, Kennedy D, Dodd F, Smith E, Lavie A, et al. The cognitive effects of supplementation with sunflower phosphatidyl serine in healthy children aged 8 to 12 years: a randomized controlled trial. Nutr J. 2025; 25(1):3. doi:10.1186/s12937-025-01264-9.

[9] Innis SM. Dietary omega 3 fatty acids and the developing brain. Brain Res. 2008; 1237:35-43. doi:10.1016/j.brainres.2008.08.078.

[10] Sherzai D, Reddy R, Sharif S, Sherzai A. A systematic review of omega-3 fatty acid consumption and cognitive outcomes in neurodevelopment. Am J Lifestyle Med. 2022; 18(1):52-70. doi:10.1177/15598276221116052.

[11] Bertoni C, Pini C, Mazzocchi A, Agostoni C, Brambilla P. The role of alpha-linolenic acid and other polyunsaturated fatty acids in mental health: a narrative review. Int J Mol Sci. 2024; 25(22):12479. doi:10.3390/ijms252212479.

[12] Waghule T, Saha RN, Alexander A, Singhvi G. Tailoring the multi-functional properties of phospholipids for simple to complex self-assemblies. J Control Release. 2022; 349:460-474. doi:10.1016/j.jconrel.2022.07.014.

[13] BCLC technical development record of the Acer truncatum seed oil-phosphatidylserine-linseed oil composite. Unpublished formulation and stability data; 2026.