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Stability-Oriented Delivery of Immune-Active Micronutrients in a Multivitamin-Mineral Tablet: Formulation Performance and Human Evidence

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Abstract: We examined the preservation of immune-relevant micronutrients in a single-layer multivitamin–mineral tablet and compared the formulation results with randomized human evidence. The tablet included vitamin C, vitamin A, vitamin D3, vitamin E, zinc and selenium in a broader micronutrient matrix. After segmented premixing, ferric-pyrophosphate preadsorption, brief low-humidity blending and direct compression, three-month retention at 40°C/75% RH was 83.7% for vitamin C and 87.2% for vitamin D3. Direct blending gave 74.8% and 82.0%, respectively. In human trials, multimicronutrient supplementation improved vitamin C and zinc status. Some nutritionally vulnerable older populations also experienced fewer infections, although functional immune assays in healthy older adults did not change. Stable formulation delivery and baseline nutritional status should therefore be considered separately when immune outcomes are assessed.

Keywords: immune nutrition, vitamin C, vitamin D3, zinc, selenium, antioxidant defense, multivitamin-mineral, BCLC

Introduction

Micronutrient status is one of several determinants of immune competence, and the relevant nutrients do not act through a single pathway. Vitamin A contributes to epithelial integrity and immune-cell differentiation; vitamins C and E participate in antioxidant defense; vitamin D is involved in immune signaling; zinc supports numerous cellular processes; and selenium is required for selenoprotein-dependent redox control. A broad review of micronutrients and the immune system emphasizes this interdependence rather than a one-nutrient explanation of immune function [1]. Zinc provides a useful example: its biological role extends from enzyme activity to immune-cell development and signaling, so the meaning of supplementation depends partly on pre-existing nutritional status [2].

Human supplementation studies also show why nutrient status and clinical response should not be treated as interchangeable outcomes. Vitamin D has been examined in relation to acute respiratory-tract infection risk [3], while vitamin C has a long intervention literature in the prevention and treatment of the common cold [4]. In institutionalized older adults, a two-year controlled study that included zinc and selenium reported fewer infectious events in the trace-element groups, a population in which baseline deficiencies were common [5]. By contrast, a 12-week multivitamin-

mineral trial in healthy adults aged 55 years or older increased vitamin C and zinc status without producing significant between-group changes across the measured bacterial-killing, phagocytosis, neutrophil reactive-oxygen-species, and related immune assays [6]. Earlier work in ambulatory older adults likewise showed that a daily multivitamin could improve circulating water-soluble vitamin status [7]. Taken together, these studies separate biochemical repletion from a universal expectation of functional immune change.

The wider multivitamin-mineral literature reinforces the same point from another angle. Combinations of vitamins and minerals have been studied for energy, fatigue, and cognition [8], for subjective mood and performance [9], and during demanding multitasking paradigms [10]; a meta-analysis has also examined stress and mood outcomes in nonclinical samples [11]. These are not direct immune endpoints, but they illustrate how the measured effect of a multinutrient product depends on the population, duration, baseline status, and endpoint selected. Trials using iron, folic acid, and vitamin B12 in adolescent girls [12], other supervised supplementation programs [13], pregnancy [14], and anemia of prematurity [15] further show that micronutrients are often delivered as combinations and judged first by whether the intended biochemical exposure is achieved.

That issue is especially relevant to a single-layer tablet containing chemically different ingredients. Label composition alone does not establish that the same exposure will be delivered after manufacture and storage. Water-soluble vitamins can be sensitive to humidity and local redox conditions, low-dose components can become nonuniform if premixing is inadequate, and an iron source can create unfavorable microenvironments when it comes into direct contact with oxidation-sensitive nutrients. Fat-soluble vitamin microcapsules present a different handling problem because prolonged or high-stress processing can weaken the physical protection intended to preserve them. For this reason, formulation stability is not a separate cosmetic property; it is part of the chain connecting the declared composition to the dose used in any later human study.

The BCLC® single-layer tablet was therefore developed around segmented premixing, ferric-pyrophosphate preadsorption, brief low-humidity blending, and direct compression. The present work first evaluates whether this process preserves selected immune-relevant micronutrients under accelerated storage and comparator conditions. The formulation findings are then placed beside controlled human evidence chosen to represent three distinct questions: correction of nutrient status, infection-related outcomes in a nutritionally vulnerable population, and functional immune assays in generally healthy older adults. This structure allows formulation performance and biological response to be discussed together without assuming that improved nutrient retention, by itself, establishes an immune effect.

Table 1. Selected active components of the representative BCLC® single-layer tablet (800 mg core).

Component	Amount per tablet
Vitamin C	55 mg
Vitamin E acetate powder	20 mg
Vitamin A acetate microcapsule powder	4 mg
Vitamin D3 microcapsule powder	6 mg
Vitamin B1 / B2 / B6	1.1 / 1.1 / 1.3 mg
Vitamin B12	2 µg
Nicotinamide	12 mg
D-calcium pantothenate	5 mg
Biotin	30 µg
Folic acid	0.4 mg
Ferric pyrophosphate	24 mg
Zinc citrate	20 mg
Selenium yeast	20 mg

Materials and Methods

1. Immune-relevant formulation components

The representative 800 mg core provided vitamin C 55 mg, vitamin E acetate powder 20 mg, vitamin A acetate microcapsule powder 4 mg, vitamin D3 microcapsule powder 6 mg, zinc citrate 20 mg and selenium yeast 20 mg. B vitamins, folic acid and ferric pyrophosphate were also present. Water-soluble vitamins, fat-soluble vitamin microcapsules, trace folate and the iron source were kept in separate premixes before final blending.

2. Accelerated stability evaluation

Tablets were stored for three months at 40°C ±2°C and 75% ±5% relative humidity. We measured retention of folic acid, vitamin C, vitamin B1 and vitamin D3 and checked the tablets for brown spotting. Direct blending, ferrous-fumarate substitution followed by direct blending, prolonged blending and high-humidity processing were used as stress comparators.

3. Human-evidence synthesis

Randomized and controlled human studies were selected to cover infection events, correction of nutrient status and functional immune assays after multimicronutrient supplementation. Positive and neutral results were interpreted within the population, duration and baseline nutritional conditions of each study.

Table 2. Human intervention evidence illustrating nutrient-status and immune-context heterogeneity.

Study	Design / population	Micronutrient	Immune-related finding
Girodon et al. 1997 [5]	81 institutionalized older adults; double-blind controlled; 2 years	Zinc + selenium, vitamins, combination, or placebo	Trace-element groups (with or without vitamins) had fewer infectious events; baseline deficiencies were common.
Fantacone et al. 2020 [6]	Healthy adults ≥55 years; double-blind randomized placebo-controlled; 12 weeks	Multivitamin/mineral containing vitamin C, zinc and vitamin D-related nutrients	Vitamin C and zinc status improved; measured bacterial killing, phagocytosis, neutrophil ROS and immune-status markers did not significantly differ from placebo.
Mann et al. 1987 [7]	101 ambulatory older adults; randomized double-blind placebo-controlled; 4	Daily multivitamin	Water-soluble vitamin status including vitamin C, B2, B12 and folate increased relative to placebo.

Results

1. Preservation of immune-active micronutrients

After accelerated storage, vitamin C retention was 83.7% and vitamin D3 retention was 87.2% in the segmented formulation; no obvious brown spots were seen. The direct-blend comparator retained 74.8% and 82.0%, respectively. Values for the ferrous-fumarate/direct-blend comparator were 72.4% and 80.5%. At 60% relative humidity, retention was 76.2% for vitamin C and 82.1% for vitamin D3, with slight brown spotting.

2. Human immune evidence

Girodon et al. followed institutionalized older adults for two years and recorded fewer infectious events in groups given zinc and selenium, either alone or with vitamins [5]. A 12-week trial in healthy older adults produced a different pattern: plasma vitamin C and serum zinc increased, but whole-blood bacterial killing, neutrophil phagocytosis, neutrophil reactive oxygen species production and selected immune-status markers did not differ significantly [6]. Mann et al. also found that oral

supplementation improved water-soluble vitamin status in older adults [7]. The studies differed in baseline insufficiency, age, outcome selection and duration.

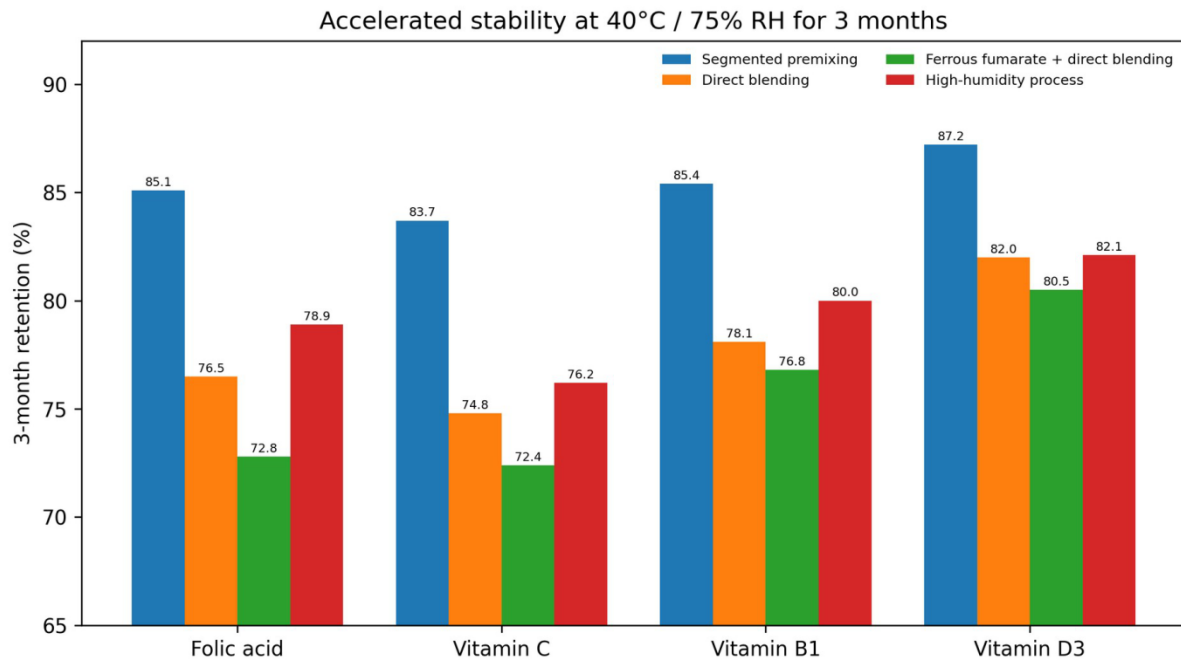


Figure 1. Accelerated-storage retention of selected micronutrients under the segmented BCLC® process and comparator conditions.

Discussion

The formulation experiment addresses a practical issue: preserving several immune-relevant micronutrients in an iron-containing single-layer tablet. Vitamin C, folate and some B vitamins are vulnerable to moisture and local redox conditions. Fat-soluble vitamin microcapsules face another problem, because physical disruption or prolonged processing can compromise their protection.

Clinical responses varied with the study population. In institutionalized older adults, where micronutrient deficiencies were common, long-term supplementation containing zinc and selenium was associated with fewer infectious events [5]. Healthy older adults showed biochemical repletion during the shorter trial without a corresponding change in every functional immune assay [6]. Nutrient reserve, intervention duration and the endpoint chosen for measurement may account for part of that difference.

Higher retention of vitamin C and D3 gives a controlled formulation for studies that measure nutrient-status biomarkers together with immune endpoints. Such studies would be most informative if baseline micronutrient status were recorded rather than treated as uniform.

Conclusion

Segmented premixing and low-humidity processing preserved immune- and antioxidant-related micronutrients better than direct blending and the higher-stress comparator conditions. Randomized human studies report improved micronutrient status and, in selected populations, fewer infection-related events. Functional immune responses were more variable and depended on baseline status and study context. The retained nutrient profile allows tablet-specific immune-nutrition studies to proceed with better-controlled nutrient delivery.

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