

oxygen levels in the body lead to competing demands between tissue oxygenation and reduced blood flow for controlling heat losses [43]. In the present study, while immediate responses of hands temperature to cold stress remained similar to baseline, iron-fortified gummy consumption effectively improved temperature recovery in hands.

Due to oxidation-reduction reactions, iron can induce unacceptable sensory changes in the food [44]. Therefore, when choosing iron carriers for fortification, a key consideration is to balance chemical stability, solubility, and bioavailability [32]. Among the four iron compounds added in the gummy under study, naturally sourced HIP is the most easily absorbable form and contributes 10% or more of our total absorbed iron [45]; pyrophosphate in FePP can enhance iron transfer from transferrin to ferritin and promote iron exchange between transferrin molecules [46]; ferrous bisglycinate allows iron absorption to be regulated physiologically by the body's iron status and is associated with fewer gastrointestinal adverse events [21,47]; NaFeEDTA remains stable during food processing and storage, and is highly bioavailable as the binding of ethylenediaminetetraacetic acid with iron partially protects the iron from the effects of inhibitors of iron absorption [48]. These properties allow them to offer a better absorption rate by the human body without modifying the individual characteristics of the food vehicle [48–50]. Participants who took the iron-fortified gummy did not experience major gastrointestinal symptoms throughout the eight weeks of intervention. Consumption of the iron-fortified gummy was not associated with any AE during the study period.

Our study was not the first randomized controlled trial that studied the effectiveness of iron-fortified foods among participants with IDA [51]. Many previous studies carried out in other countries have proven the positive effects of iron-fortified foods on alleviating IDA symptoms and on many other aspects of the user's

health condition [52–58]. However, by focusing on Chinese young women with IDA, our study offers additional support for the positive health benefits of iron-fortified foods within this population. Additional studies may be conducted on other target groups such as children or pregnant women to further study the efficacy of this iron-fortified gummy. We chose the form of a soft candy as the food vehicle for iron fortification. The product is easy to consume and has a good taste, making it well accepted by the general population. Moreover, we involved non-invasive bioengineering devices which were not often seen in food nutrition studies to measure skin biophysical characteristics. Through these methods, we showed that iron supplementation not only increased body hemoglobin level, but also improved skin conditions. Despite the positive results from the present study, some limitations need to be addressed in future research. Iron absorption is affected by nutrients and compounds consumed from daily diet. While ascorbic acid, lactic acid and animal meat factors promote iron absorption, phytates in wholegrains, polyphenols in tea and coffee, proteins from soya bean, milk, eggs and calcium are known inhibitors for iron absorption [59]. Adjusted or stratified analysis with the composition of the diet concerning the content of inhibitors/promoters of iron absorption might be necessary to explore the effect of the gummy product in real world applications.

CONCLUSION

In conclusion, our findings suggested that continuous consumption of the Minayo iron-fortified gummy under study could help build up blood iron levels to generate hemoglobin and relieve IDA-related symptoms in young Chinese women. The gummy intake effectively improved skin barrier functions, skin complexions and temperature regulation in hands, and had a positive impact on the user's quality of life and satisfaction with their health. Our study showed a feasible method to deliver iron daily, gradually increase body iron levels, and provide

sustainable long-term benefits. The efficacy of the iron-fortified gummy in other target groups and its association with diet compositions require further exploration in future studies.

Abbreviations: AE: adverse event, AL T: alanine aminotransaminase, ANOVA: analysis of variance, AST: aspartate aminotransferase, BMI: body mass index, CI: confidence interval, FePP: ferric pyrophosphate, GSRS: Gastrointestinal Symptom Rating Scale, HIP: heme iron polypeptide, ID: iron deficiency, IDA: iron deficiency anemia, MCH: mean corpuscular hemoglobin, MCHC: mean corpuscular hemoglobin concentration, MCV: mean corpuscular volume, MET: metabolic equivalent of task, NaFeEDTA: sodium ferric ethylenediaminetetraacetate, SAE: serious adverse event, SCH: stratum corneum hydration, SD: standard deviation, SE: standard error, TEWL: transepidermal water loss, TIBC: total iron binding capacity, TSAT: transferrin saturation, UIBC: unsaturated iron binding capacity, WHO: World Health Organization, WHOQOL-BREF: World Health Organization Quality of Life-BREF.

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