



OPEN Qualitative attributes, nutritional traits and yield components of *Calendula officinalis* L.: response to liquid NPK fertilizer, humic acid, and moringa leaf extract

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Calendula officinalis L. is an economic annual or biennial herbaceous medicinal plant which is widely cultivated in the world due to its medicinal and ornamental assets of flowers. In order to improve flower yield and quality, a two-sectional factorial experiment (CRD, $r=3$) was conducted in Mosul, Iraq, in 2023. The plants were exposed to different fertilization: Factor A; NPK Liquid Fertilizer (0:33:42) (1.5- and 3-mL L⁻¹) and Factor B; Moringa leaf extract at 0-, 2-, and 4-mL L⁻¹ (section a) and in section b were exposed to 0, 1.5, and 3 g L⁻¹ Humic acid and Moringa leaf extract at 0-, 2-, and 4-mL L⁻¹. The liquied NPK fertilizer (CF), Moringa extract (ME) and Humic acid (HA), as well as their interactions, significantly improved vegetative growth, flowering and phytochemical properties of flowers. In section a, the highest plant height (16.66 cm) was obtained with application of 3 mL L⁻¹ liquied NPK fertilizer without extract, branch number (13.33) with 3 mL L⁻¹ CF + 4 mL L⁻¹ ME, SPAD (43.54 value) 3 mL L⁻¹ CF + 2 mL L⁻¹ ME, flower diameter (73.75 mm) 3 mL L⁻¹ CF + 0 mL L⁻¹ ME, fresh flower weight (270 g) 3 mL L⁻¹ CF + 2 mL L⁻¹ ME, flower dry weight (100 g) 1.5 mL L⁻¹ CF + 4 mL L⁻¹ ME, carotene content (0.86%) 1.5 mL L⁻¹ CF + 4 mL L⁻¹ ME and 3 mL L⁻¹ CF + 2 mL L⁻¹ ME, phosphorus (0.359%) and potassium (1.39%), and nitrogen content (2.47%) in 3 mL L⁻¹ CF + 4 mL L⁻¹ ME. In second experiment (b), the responses of different traits to treatments were less diverse, so that the combined application of 3 g L⁻¹ humic acid and 2- or 4-mL L⁻¹ moringa extract consistently produced the greatest improvements across vegetative, reproductive, and biochemical traits, demonstrating a strong synergistic effect on the growth and quality of *C. officinalis*. Furthermore, the PCA results demonstrated the superior performance of Humic acid 3 g L⁻¹ × Moringa extract 2 mL L⁻¹, highlighting the importance of combining higher humic acid levels with moderate Moringa extract concentrations to maximize nutrient assimilation, vegetative growth, and reproductive output. Furthermore, the HPLC analysis indicated that the synergistic application of liquied NPK fertilizer or humic acid with 4 mL L⁻¹ of Moringa extract promotes the biosynthesis of key phenolic metabolites in *C. officinalis*.

Keywords Biostimulants, Medicinal plants, Pot marigold, Phenolic compounds, Sustainable agriculture

Marigold (*Calendula officinalis* L.), a medicinal plant belonging to the Asteraceae family, is an annual or biennial herbaceous plant native to Mediterranean areas, Europe and China^{1,2}. This plant is extensively cultivated in the world, including Middle East, Africa and United States³. Pot marigold is an economic plant due to ornamental and medicinal properties of flowers, which is rich in bioactive compounds and essential oils⁴⁻⁶. It is a main source of various bioactive constituents including coumarins, quinones, carotenoids, terpenoids, and flavonoids⁶. *Calendula officinalis* is extensively used as analgesic, antiseptic, and anti-inflammatory agents, especially to treat inflammations of oral and pharyngeal mucosa, skin injuries, and burns⁶.

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