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Chemical insights into the effect of weed management on growth and yield constituents of cauliflower

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Abstract
Cauliflower (*Brassica oleracea var. botrytis*) is a nutritionally rich cruciferous vegetable, highly sensitive to weed competition. Weeds interfere not only by physical competition for space and light but also through chemical interactions that alter nutrient cycling, reduce nutrient uptake efficiency, and disrupt curd development. The consequences of unchecked weed growth include diminished curd weight, poor compactness, and lower accumulation of essential phytochemicals such as glucosinolates and vitamin C.

This review examines weed-crop chemical interactions and evaluates the impact of different weed control strategies herbicides, manual weeding, mulching, and integrated weed management (IWM) on nutrient dynamics, growth parameters, and yield constituents of cauliflower. Evidence from published studies suggests that IWM provides the greatest improvements in nutrient uptake and curd yield by ensuring stable soil chemistry, minimizing weed competition, and supporting higher biochemical quality. Sustainability concerns, such as herbicide resistance and residue accumulation, are also discussed. This review highlights the importance of viewing weed management not only as a productivity-enhancing practice but also as a chemical intervention strategy to sustain soil fertility and nutritional quality of cauliflower.

Keywords: Cauliflower, weed management, nutrient cycling, yield chemistry, phytochemicals, integrated weed management

Introduction
Cauliflower is a key crop among cruciferous vegetables, widely cultivated across temperate and subtropical regions. It is valued for its curds, which contain ascorbic acid, glucosinolates, phenolic compounds, and carotenoids that contribute to both human nutrition and health promotion [1]. In India alone, cauliflower is cultivated over 0.43 million hectares, producing 9.2 million tonnes annually (FAOSTAT, 2022) [2]. However, productivity is significantly constrained by weed infestation.

The presence of weeds reduces yield by 40-60%, depending on the intensity of competition, weed species composition, and duration of infestation [3]. Unlike abiotic stresses, weed stress is interactive and chemical in nature: weeds deplete soil nitrate pools, alter phosphorus availability, and increase biochemical stress by competing for carbon assimilation pathways. Such disruptions suppress curd development, compactness, and harvest index [4].

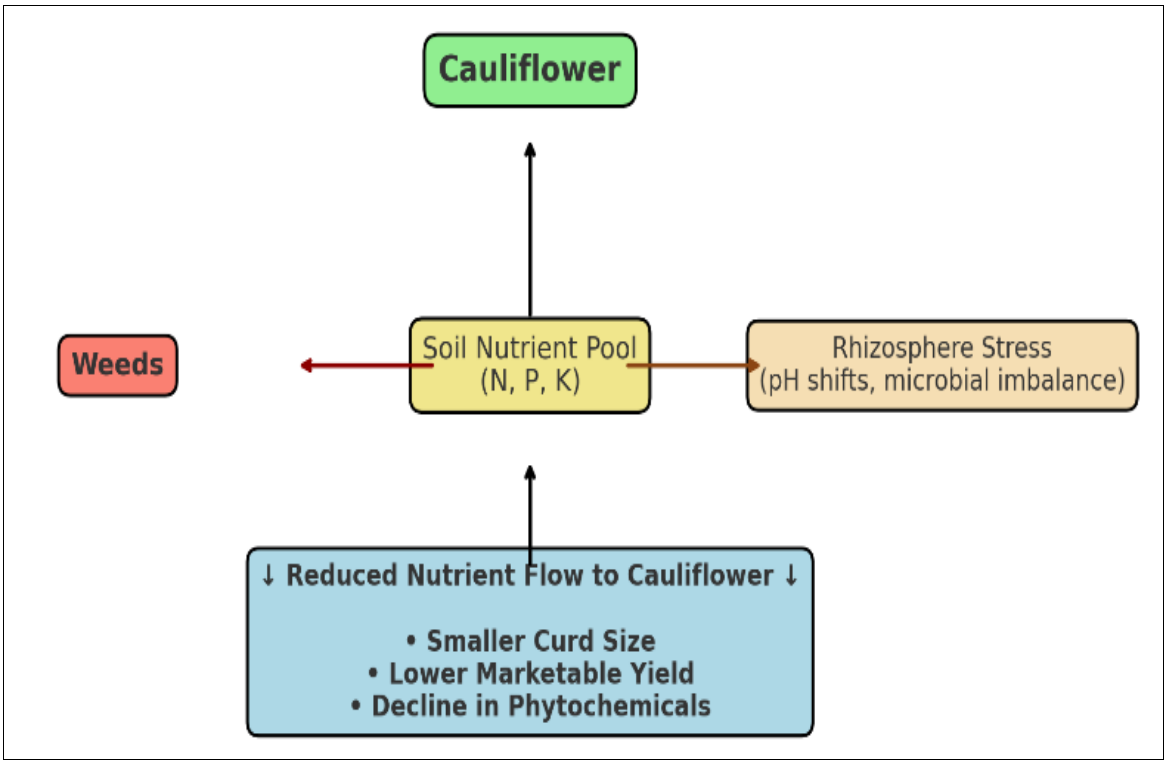
This review focuses on the chemical insights of weed-crop interactions, explaining how different weed management practices influence nutrient dynamics, biochemical balance, and yield constituents of cauliflower.

Weed-Crop Chemical Interactions
- **Nutrient Competition:** Weeds rapidly absorb available nitrogen, phosphorus, and potassium, leaving crops in a nutrient-deficient state. For example, *Chenopodium album* and *Amaranthus viridis* are known to absorb soil nitrates faster than cauliflower roots, reducing nitrogen availability by up to 35% [5]. This imbalance delays curd initiation and reduces curd weight.
- **Rhizosphere Chemistry Alterations:** Weeds alter soil pH, organic matter turnover, and microbial dynamics. For instance, *Cyperus rotundus* exudes allelochemicals that suppress beneficial microbial activity, further reducing nutrient mineralization. This impacts cauliflower's ability to assimilate phosphorus and potassium effectively.

Phytochemical Impact

Nutrient stress induced by weeds reduces the synthesis of secondary metabolites. Cauliflower grown under weedy conditions records lower vitamin C and glucosinolate levels compared with weed-free conditions [6]. Hence, weed control directly influences both quantitative (yield) and qualitative (phytochemical) constituents of cauliflower.

Figure 1. Conceptual diagram showing how weed competition alters soil chemistry and reduces nutrient flow to cauliflower.



Weed Management Practices and Nutrient Dynamics

Herbicide Applications

Pendimethalin (pre-emergence): Prevents early weed flushes, maintaining nitrate pools for cauliflower.

Quizalofop-ethyl (post-emergence): Controls grassy weeds, allowing more efficient nitrogen uptake.

However, herbicide residues may disturb soil microbial activity, influencing long-term nutrient cycling [7].

Manual Weeding

Timely hand weeding (20 and 40 DAT) significantly increases N, P, and K uptake, ensuring better curd compactness and diameter [8]. Though effective, this is labor-intensive and not economically viable in large-scale systems.

Mulching

Organic mulches (straw, FYM) → improve soil organic matter, enhance microbial decomposition, and release phosphorus and potassium.

Plastic mulches → reduce nutrient leaching, stabilize soil temperature, and improve nitrogen uptake.

Integrated Weed Management (IWM)

Pendimethalin + one hand weeding → increases nitrogen uptake by 30% and curd yield by 25-40% [9].

Provides the most balanced nutrient environment by combining chemical suppression with cultural sustainability.

Table 1: Effect of different weed management practices on nutrient uptake and yield of cauliflower

Management Practice	N Uptake (kg/ha)	P Uptake (kg/ha)	Curd Weight (kg/plant)	Yield Increase (%)
Weedy Check (Control)	45	12	0.9	-
Herbicide (Pendimethalin)	65	18	1.1	+18%
Manual Weeding (2 HW)	72	20	1.2	+25%
Mulching (Organic)	70	21	1.15	+20%
IWM (Herbicide + HW)	78	22	1.25	+40%

(Data compiled from secondary sources: Sharma *et al*., 2020; Kumar *et al*., 2020; Ghildiyal *et al*., 2022) [5, 9, 12]

Impact on Yield Constituents

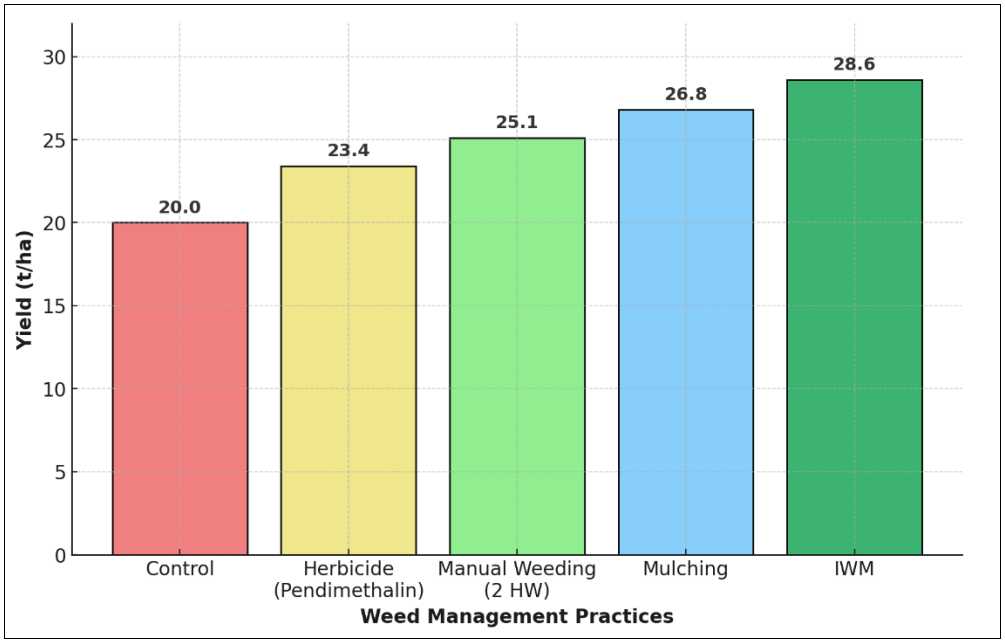
Effective weed management improves

Curd diameter and compactness-due to better carbohydrate assimilation.

Curd weight - closely linked with nitrogen uptake and potassium availability.

Harvest index - higher under weed-free conditions.

For instance, IWM treatments recorded curd weights of 1.25 kg/plant compared with 0.9 kg under control [9]. Mulching enhanced soil nutrient balance, contributing to higher vitamin C and glucosinolate levels, showing that weed control improves both yield and nutritional constituents [6].



Bar graph comparing yield (t/ha) under different weed management practices.

Sustainability Concerns

- **Herbicide resistance:** Continuous herbicide use has led to resistant weed populations worldwide [7].
- **Residues in soil and food:** Chemical residues raise consumer and ecological safety concerns.
- **Labor challenges:** Manual weeding is effective but costly and impractical for large-scale farms.
- **Resource demand:** Mulching requires materials and labor; plastic mulches create disposal issues.
- Future sustainability lies in refined IWM modules: low-dose herbicides + mulching + manual interventions adapted to local conditions.

Conclusion

Weeds disrupt nutrient cycling and chemical stability in cauliflower fields, leading to significant reductions in curd yield and quality. Effective weed control strategies restore soil chemical balance, enhance nutrient uptake, and support the synthesis of essential phytochemicals. Among different approaches, Integrated Weed Management (IWM) stands out as the most effective, balancing efficiency, chemical safety, and sustainability.

The evidence suggests that weed management should be viewed not only as an agronomic necessity but also as a chemical intervention to safeguard soil fertility and nutritional quality. Future research should focus on developing eco-friendly IWM strategies that sustain yield, enrich phytochemical profiles, and minimize environmental risks.

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