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INFLUENCE OF PHENOLOGICAL STAGE ON BIOACTIVE COMPOSITION IN *MENTHA* × *PIPERITA* L. CULTIVARS 'CORDIAL' AND 'CRISTAL'

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Abstract

Mentha × piperita L. is a valuable aromatic species rich in bioactive volatile compounds. This study evaluated the influence of phenological stage and genotype on biomass, essential oil composition, total phenolic content, total flavonoid content, and antioxidant capacity in two cultivars, 'Cordial' and 'Cristal'. Plants were harvested at vegetative growth (BBCH 31-39), bud stage (BBCH 51-59), and full flowering (BBCH 65). Essential oils were analyzed by GC-MS, and antioxidant capacity was related to phenolic content. Results showed that both factors significantly influenced all parameters. 'Cristal' exhibited higher biomass production, while 'Cordial' showed greater accumulation of secondary metabolites and higher antioxidant capacity. Antioxidant activity strongly correlated with total phenolics. These findings highlight the importance of cultivar selection and harvest stage depending on whether biomass yield or phytochemical quality is targeted.

Key words*: essential oil, antioxidant capacity, phenolic content, Mentha x piperita, phenological stage, GS-MS.*

INTRODUCTION

The genus *Mentha* (Lamiaceae) is among the most taxonomically complex groups of aromatic plants, comprising approximately 18–19 species and over 11 natural hybrids, characterized by high morphological plasticity and extensive interspecific hybridization (Božović et al., 2015; Mogosan et al., 2017). This genetic and morphological diversity underlies the remarkable variability observed in agronomic performance and chemical composition among mint species and cultivars.

In Romania, peppermint cultivation has a long-standing tradition dating back to 1908, encompassing economically important species such as *Mentha piperita*, *M. spicata*, and *M. suaveolens* (Moldovan & Oprean, 2014). Breeding programs conducted at the Fundulea station have resulted in the development of high-performance cultivars including 'Cordial', 'Columna', 'Cristal', 'Coral', 'Mencris', and 'Record', characterized by high menthol content and productivity. Among these, 'Cordial' and 'Cristal' are widely cultivated due to their stable oil quality, elevated menthol levels, and resistance to fungal diseases. 'Cordial', registered in 1989, is a medium-tall plant with robust purple stems and elongated leaves, producing 98-150 q ha^{-1} fresh herbage, with an essential oil content of 2.0-4.3% and menthol concentrations ranging from 49-70%. 'Cristal', registered in 2000 and derived from 'Cordial' × *Mentha arvensis* hybrids, exhibits a compact growth habit, strong regenerative capacity, and resistance to rust and powdery mildew, with productivity of 95-170 q ha^{-1} fresh herbage, essential oil content of 4.4-4.9%, and menthol levels of 49-75%, making it suitable for industrial steam distillation and mechanized harvesting systems (Păun et al., 1988). The chemical diversity and high menthol content of these cultivars directly influence both yield and pharmacological properties, highlighting the link between breeding, cultivation, and industrial and therapeutic applications.

The diversity of the genus is also reflected in the pronounced chemical polymorphism of its essential oils, typically classified into menthol-, menthone-, carvone-, or linalool-type chemotypes, each derived from distinct biosynthetic pathways (Božović et al., 2015). Peppermint essential oil is a complex mixture of volatile compounds, predominantly monoterpenes and phenolic derivatives, with menthol and menthone as the principal bioactive constituents. Variability in volatile composition, including compounds such as α-terpinolene and terpinen-4-ol, further expands its functional profile and industrial applicability (Ali et al., 2019; Pintilia et al., 2025).

In addition to volatile fractions, *Mentha* species accumulate significant amounts of non-volatile phenolic compounds, particularly phenolic acids and flavonoids, which substantially contribute to biological activity. The antioxidant mechanisms of *Mentha* polyphenols involve free radical scavenging through hydrogen atom or electron donation, inhibition of lipid peroxidation, and chelation of pro-oxidant metal ions (Dorman et al., 2003; Shan et al., 2005). Rosmarinic acid and flavonoid derivatives have also been shown to modulate endogenous antioxidant defense systems and reduce oxidative stress markers in biological models (Kapp et al., 2013). Consistently, a positive correlation has been reported between total phenolic and flavonoid content and the overall antioxidant capacity of mint extracts (Mimica-Dukić et al., 2003).

The accumulation of both volatile and non-volatile metabolites in *Mentha* is strongly influenced by genotype, environmental conditions, cultivation practices, and developmental stage. Variations in light intensity, temperature, and water availability can significantly affect phenylpropanoid and terpenoid metabolism, thereby altering antioxidant potential and essential oil composition (Shan et al., 2005). Biomass production is generally higher under conventional systems, whereas organically cultivated peppermint often exhibits increased essential oil content, likely due to moderate stress stimulating secondary metabolism (Oroian et al., 2017). Climatic variability, particularly elevated temperatures, may enhance oil biosynthesis but also induce qualitative changes, such as reduced menthol content and increased pulegone or menthyl acetate levels, alongside significant shifts in menthone and menthofuran concentrations (Heydari et al., 2018).

Phenological stage represents another critical factor influencing both yield and chemical quality. Essential oil composition and content can vary substantially depending on harvest timing, with the flowering stage frequently associated with maximal oil accumulation and modifications in the relative proportions of key monoterpenes such as menthol and menthone (Sourestani, 2016). Moreover, combined hydric and thermal stress may impair shoot regrowth and canopy development, preventing plants from reaching technological maturity for subsequent harvests and ultimately reducing productivity.

Due to their flavoring properties and a wide spectrum of biological activities, *Mentha* species are extensively used in the food, pharmaceutical, and cosmetic industries. Peppermint essential oil exhibits antimicrobial, antioxidant, neuroprotective, anti-inflammatory, and therapeutic effects (Mogosan et al., 2017; Hudz et al., 2023). Pharmacological studies have demonstrated antispasmodic, carminative, and sedative properties, smooth muscle relaxation relevant to irritable bowel syndrome, as well as cardioprotective, hypotensive, and hypolipidemic effects associated with antioxidant mechanisms (McKay & Blumberg, 2006; Hudz et al., 2023; Malcheva et al., 2023). Despite the recognized industrial and medicinal importance of peppermint, relatively few studies have systematically evaluated how phenological development influences essential oil composition, alongside the accumulation of other bioactive compounds such as polyphenols and flavonoids. A comprehensive understanding of these variations is essential for optimizing harvest timing, improving oil quality, and maximizing therapeutic potential.

Therefore, the present study aimed to evaluate the influence of developmental stage on essential oil composition, biomass production, and the concentration of key constituents such as menthol and menthone in the peppermint cultivars 'Cordial' and 'Cristal'. Additionally, total polyphenol and flavonoid contents were assessed in relation to antioxidant capacity, in order to clarify how phenological development modulates the industrial and therapeutic value of these cultivars.

MATERIALS AND METHODS

Plant material

The plant material consisted of two Romanian peppermint (*Mentha piperita* L.) cultivars, 'Cordial' and 'Cristal', both developed through national breeding programs. The plants were grown at the National Agricultural Research and Development Institute Fundulea (NARDI Fundulea), Romania, in the experimental field dedicated to the maintenance and renewal of the medicinal and aromatic plant germplasm collection.

The experimental plots were arranged in a randomized complete block design with three replicates per cultivar, each plot having a harvestable area of 5 m². Planting followed standard agronomic practices recommended for peppermint cultivation to ensure uniform plant density and optimal soil moisture conditions. Two planting dates were included to evaluate potential interactions between planting time and phenological development.

Harvesting was conducted four times during the 2025 growing season, corresponding to key phenological stages: *intensive vegetative growth (BBCH 31-39), floral bud stage (BBCH 51-59), and full flowering*, and full flowering stage (25 June). Fresh herbage yield was recorded for each plot at each harvest, and cumulative yield was subsequently calculated.

The characterization of fresh mint leaves was carried out at the Research Center for Studies of Food Quality and Agricultural Products, from the University of Agronomic Sciences and Veterinary Medicine of Bucharest.

The methods, summarized in Table 1, included the determination of shoot density, fresh mass, dry matter content, total phenolic and flavonoid contents, essential oil yield, essential oil composition, and antioxidant capacity.

Table 1. Analytical methods used for the determination of biometric, phytochemical, and antioxidant parameters

No.	Property	Symbol	Unit	Determination Technique / Equipment	Reference
1	Shoot density	S	Shoots m^{-2}	Counting shoots within a single 1 m² quadrat;	Kent, 2012
2	Fresh mass	FM	g m^{-2}	Aerial biomass harvested from a single 1 m²; weighed immediately using an analytical balance	FAO, 2006
3	Dry mass	DM	%	Oven-drying at 105°C until constant mass	AOAC 934.01,2016
4	Total phenolic content	TPC	mg gallic acid equivalent (GAE) g^{-1}	Folin–Ciocâlteu method; UV–Vis spectrophotometer (760 nm)	Perez et al., 2023
5	Total flavonoid content	TFC	mg rutin equivalents (RE) g^{-1}	$AlCl_3$ colorimetric assay; UV–Vis spectrophotometer (510 nm)	Chang et al., 2002
6	Essential oil yield	EO	% (mL/100 g)	Hydrodistillation (3 h) using a Clevenger apparatus	Adams, 2007
7	Essential oil composition	EOC	%	Gaz chromatography (GC-MS)	Ion et al., 2020
8	Antioxidant capacity	AC	mg trolox equivalents (TE) g^{-1}	DPPH assay; UV-Vis spectrophotometer (515 nm)	Bujor et al., 2016

All replicated measurements, namely total phenolic content, total flavonoid content, and antioxidant capacity, were performed in triplicate, and the results are presented as mean ± standard deviation (SD). In contrast, shoot density, fresh mass, dry mass, essential oil yield, and essential oil composition were each determined from a single measurement. Accordingly, these latter data are reported descriptively, and no inferential statistical analyses were applied; therefore, they should be interpreted as indicative.

RESULTS AND DISCUSSIONS

Growth and biomass of peppermint cultivars

During the intensive vegetative growth stage, the 'Cristal' cultivar exhibited a higher shoot density (393 shoots m^{-2}) compared with 'Cordial' (235 shoots m^{-2}), whereas 'Cordial' showed slightly higher fresh and dry biomass per plant (Table 2). This suggests a genotype-specific allocation strategy, with 'Cristal' investing more in shoot proliferation and 'Cordial' allocating resources toward greater

biomass accumulation per shoot. Such variability among mint genotypes is consistent with the high phenotypic plasticity reported for *Mentha* species (Telci et al., 2004).

At the bud formation stage, both cultivars demonstrated a marked increase in fresh biomass, particularly 'Cristal', which reached 3,923 g m^{-2} fresh mass compared with 2,221 g m^{-2} in 'Cordial'. This stage corresponds to an optimal period for vegetative growth under favorable climatic conditions, characterized by longer daylength and adequate water availability (Telci et al., 2004). However, dry mass values were lower than those observed at flowering, reflecting the higher water content of plant tissues during this phase. These results agree with Zheljazkov et al. (2010), who reported that the first harvest at bud formation typically provides the highest fresh herbage and essential oil yields due to optimal regrowth conditions and sufficient physiological time for biomass accumulation.

Table 2. Peppermint growth and biomass at different growth stages

Cultivar	Shoots (m^{-2})	Fresh mass (g m^{-2})	Dry mass (%)
Intensive growth (BBCH 31-39			
'Cristal'	393	500	22.92
'Cordial'	235	560	24.92
Bud formation (BBCH 51-59)			
'Cristal'	308	3,923	15.52
'Cordial'	194	2,221	17.54
Flowering (BBCH 65)			
'Cristal'	280	1,685	38.87
'Cordial'	235	2,313	33.33

During the flowering stage, both cultivars showed a reduction in shoot density, accompanied by decreased fresh mass but a pronounced increase in dry mass, particularly in 'Cristal' (38.87%). This pattern reflects progressive tissue lignification and a higher proportion of structural dry matter, a common phenomenon in advanced phenological stages. Similar trends were reported by Nazem et al. (2019), who observed lower fresh herbage yields at later growth stages despite increased dry matter concentration. Additionally, Zheljazkov et al. (2010) demonstrated that harvesting at flowering generally results in lower essential oil yields compared with bud formation, largely due to reduced regrowth capacity and shorter recovery periods.

Bioactive compound variation

During the intensive vegetative growth stage, the 'Cordial' genotype exhibited a markedly higher total phenolic content (15.17 ± 0.13 mg GAE g^{-1}) compared with 'Cristal' (6.64 ± 0.42 mg GAE g^{-1}), suggesting an early activation of secondary metabolism in 'Cordial', likely associated with antioxidant protection of rapidly developing tissues (Figure 1). Phenolic compounds play a key role in protecting young plant organs against oxidative stress and environmental constraints (Farnad et al., 2014; Dirar et al., 2019).

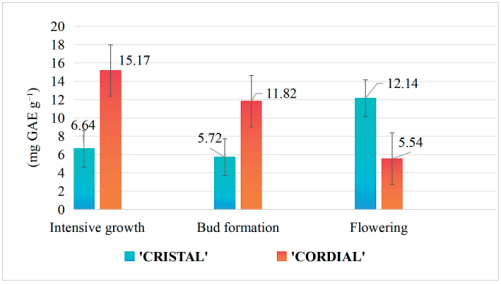

Figure 1. Total phenolic content of fresh mint leaves. Columns represent mean values (N = 3); bars indicate ± standard deviation (SD)

At the bud formation stage, TPC increased in 'Cristal' (5.72 ± 0.58 mg GAE g^{-1}), while 'Cordial' showed a decrease (11.82 ± 0.10 mg GAE g^{-1}). This shift reflects a genotype-specific metabolic response during the transition from vegetative to reproductive growth. Phenolic biosynthesis is strongly influenced by developmental stage, and the onset of reproductive development may stimulate phenolic accumulation as an adaptive response to increased physiological stress (Kaddour et al., 2022; Abidi, 2025).

During flowering, 'Cristal' reached its highest TPC value (12.14 ± 0.46 mg GAE g^{-1}), whereas 'Cordial' recorded its lowest level (5.54 ± 0.38 mg GAE g^{-1}). In 'Cristal', phenolic synthesis appears enhanced toward plant maturity, likely as a protective mechanism against elevated oxidative stress associated with higher

temperatures and increased metabolic demand. Similar responses have been observed in *Mentha spicata* subjected to thermal and water stress, where polyphenol accumulation increased under adverse conditions (Katar et al. 2017).

In southeastern Romania, a maximum air temperature of 30°C recorded in May, combined with total monthly precipitation of 89 mm (INCDA Fundulea weather station), can create conditions conducive to moderate thermal and transient water stress, depending on rainfall distribution and soil water-holding capacity. Although 89 mm may appear sufficient at the monthly scale, uneven rainfall distribution or short dry intervals between precipitation events can limit effective soil moisture availability during active vegetative growth.

Considering total flavonoid content, the 'Cordial' cultivar exhibited substantially higher levels (164.27 ± 4.79 mg RE g^{-1}) than 'Cristal' (51.80 ± 2.17 mg RE g^{-1}) during the intensive vegetative growth stage, indicating an early activation of flavonoid biosynthesis likely associated with the protection of rapidly expanding tissues against oxidative stress (Figure 2). Comparable trends have been reported in other species (*Morus alba*, *Cyperus rotundus*, *Blepharis linariifolia*), where young organs accumulate elevated flavonoid concentrations as a defensive strategy against environmental and oxidative challenges (Dirar et al., 2019).

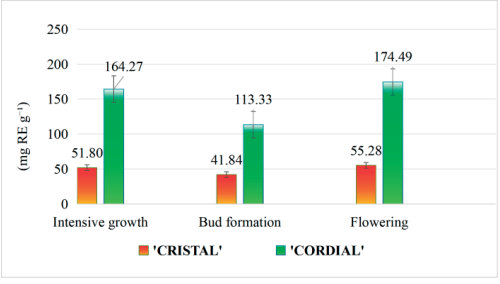

Figure 2. Total flavonoid content of fresh mint leaves. Columns represent mean values (N = 3); bars indicate ± standard deviation (SD)

At the bud formation stage, TFC decreased in both cultivars; however, 'Cordial' maintained higher levels (113.33 ± 2.26 mg RE g^{-1}) than 'Cristal' (41.84 ± 3.38 mg RE g^{-1}). This pattern reflects genotype-dependent modulation of secondary metabolism during the transition from vegetative to reproductive growth. Flavonoid biosynthesis is highly sensitive to developmental metabolic reprogramming and the plant's capacity to synthesize phenolic derivatives under changing physiological demands (Farnad et al., 2014).

During the flowering stage, TFC increased again, reaching maximal values in 'Cordial' (174.49 ± 6.38 mg RE g^{-1}), whereas 'Cristal' showed a moderate increase (55.28 ± 4.29 mg RE g^{-1}). The late-stage accumulation in 'Cordial' may confer enhanced tolerance to oxidative stress associated with reproductive development. Such trends are consistent with previous studies linking elevated flavonoid production at advanced developmental stages to stress-defense mechanisms and intensified secondary metabolism (Dirar et al., 2019).

Antioxidant capacity

Antioxidant capacity (Figure 3) was influenced by both phenological stage and genotype. In the 'Cristal' cultivar, antioxidant capacity increased markedly from 34.50 ± 1.27 mg TE g^{-1} during intensive growth to 101.89 ± 4.83 mg TE g^{-1} at bud formation, followed by a substantial decline to 54.52 ± 1.98 mg TE g^{-1} at flowering. In contrast, 'Cordial' consistently exhibited considerably higher values across all developmental stages, reaching 186.57 ± 1.04 mg TE g^{-1} during intensive growth, 183.64 ± 4.15 mg TE g^{-1} at bud formation, and 162.46 ± 1.12 mg TE g^{-1} at flowering.

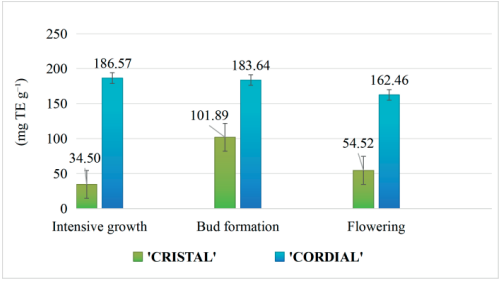

Figure 3. Antioxidant capacity of fresh mint leaf extracts. Columns represent mean values (N = 3); bars indicate ± standard deviation (SD)

Antioxidant capacity reached its maximum at the bud formation stage in 'Cristal', whereas in 'Cordial' the highest values were recorded during intensive vegetative growth and remained comparably high at bud formation, followed by a decline at flowering. Throughout

all phenological stages, 'Cordial' maintained substantially greater antioxidant capacity than 'Cristal'. This stage-dependent pattern likely reflects enhanced accumulation of phenolic compounds in young, metabolically active tissues, followed by metabolic reallocation toward reproductive development. Comparable developmental trends have been reported in *Mentha* species (Božović et al., 2015; Jianu et al., 2021).

Total phenolic content, total flavonoid content, and antioxidant capacity exhibited clear genotype- and stage-dependent variation. During intensive vegetative growth, 'Cordial' showed substantially higher phenolic and flavonoid levels than 'Cristal', corresponding to markedly greater antioxidant capacity. At bud formation, antioxidant capacity peaked in 'Cristal' despite comparatively lower phenolic concentrations, suggesting the contribution of additional antioxidant constituents, while 'Cordial' maintained consistently high activity. During flowering, 'Cordial' reached maximal flavonoid levels and retained superior antioxidant capacity, whereas 'Cristal' showed a weaker correspondence between phenolic content and AA. Overall, antioxidant capacity was more closely associated with flavonoid accumulation in 'Cordial', while in 'Cristal' the relationship appeared less direct and likely influenced by other bioactive compounds.

Environmental stress during early vegetative stages may further stimulate phenolic biosynthesis, enhancing antioxidant potential, as observed in *Mentha spicata* grown under arid conditions (Kaddour et al., 2022). The consistently higher antioxidant capacity in 'Cordial' suggests genotype-dependent differences in secondary metabolism, consistent with previous findings in *Mentha* cultivars (Jianu et al., 2021). The lower values recorded in 'Cristal', particularly at flowering, likely reflect reduced phenolic accumulation at this stage.

Phenological stage also strongly affected biomass production and essential oil characteristics. Vegetative stages were associated with higher shoot density and fresh biomass, especially in 'Cristal', whereas the transition to reproductive development corresponded with intensified secondary metabolite synthesis. Such shifts are consistent with reports indicating that metabolic flux is redirected from primary growth to essential oil biosynthesis during reproductive phases (Zheljazkov et al., 2010; Oroian et al., 2017).

Essential oil yield and composition

The data show that essential oil yield varies both with cultivar and phenological stage. In the early vegetative stage, 'Cordial' exhibits slightly higher EO content (0.62%) than 'Cristal' (0.54%), suggesting that 'Cordial' initiates oil biosynthesis earlier during leaf expansion, likely reflecting a genotype-dependent activation of monoterpene pathways.

At the bud formation stage, EO yield decreases in 'Cristal' (0.41%) while remaining relatively stable in 'Cordial' (0.60%). This divergence may indicate a temporary metabolic shift in 'Cristal', where assimilates are preferentially allocated toward biomass and reproductive organ development, temporarily reducing oil accumulation. In contrast, 'Cordial' maintains a more stable oil production during this stage, reflecting a consistent investment in secondary metabolism.

During flowering, EO yield increases markedly in 'Cristal' (1.52%), surpassing 'Cordial' (1.10%). This trend highlights that flowering is a critical phenophase for essential oil accumulation, particularly in 'Cristal', when metabolic flux is redirected toward the production of volatile compounds. The higher oil content at flowering may be associated with increased monoterpene synthase activity and enhanced metabolic demand linked to reproductive growth (Rasooli et al., 2002; Singh et al., 2009; Verma et al., 2010).

The analysis of volatile oil composition revealed pronounced qualitative and quantitative differences between the two cultivars, indicating distinct chemotypic orientations (Figure 4). In 'Cordial', oxygenated monoterpenes dominated throughout all phenological stages, with menthol and menthone as the principal constituents (Figure 4a). Menthol content increased progressively from the intensive growth stage (33.77%) to flowering (46.19%), whereas menthone remained relatively stable (28.54-31.03%). This shift toward higher menthol levels at flowering is consistent with reports showing that menthol accumulation intensifies from early to late bloom, while

menthone, its biosynthetic precursor, tends to stabilize or decline as enzymatic conversion progresses (Grulova et al., 2015). A moderate increase in menthofuran at the bud formation stage (2.88%) suggests a temporary diversion of metabolic flux toward secondary side-pathways, a phenomenon associated with developmental stage and environmental factors such as temperature and water availability (Taherpour et al., 2017). Sesquiterpenes, including caryophyllene and germacrene D, were present only in low proportions (1.91% and 0.97%, respectively), confirming that 'Cordial' retains a classical "menthol-type" peppermint oil profile comparable to those described by Mahboubi & Kazempour (2014). The presence of D-limonene, isomenthone, neo-menthol, (±)-menthol, isomenthol, neoisomenthol (*tentative identification*), piperitone, and menthyl and isomenthyl acetates further supports a strong metabolic flux toward menthone reduction and menthol ester formation, characteristic of high-quality peppermint oil.

In contrast, 'Cristal' exhibited a markedly different chemical profile (Figure 4b), dominated by linalool across all phenological stages (50.55-65.25%), indicating a chemotype distinct from 'Cordial'. Genotype-driven variation in essential oil composition is widely reported in *Mentha* species and is attributed to genetic regulation of terpene synthase activity (Nazem et al., 2019). 'Cristal' was characterized by compounds associated with the carvone biosynthetic pathway, including 1,8-cineole, γ-terpinene, (-)-borneol, terpinen-4-ol, cis-dihydrocarvone, citronellol, pulegone, carvone, geranial, neodihydrocarveol (*tentative identification*), and dihydrocarvyl acetate. Carvone content increased substantially from the intensive growth stage (5.81%) to bud formation and flowering (~16.5%), suggesting activation of the limonene–carvone metabolic route. Such developmental shifts in monoterpene composition are consistent with previous studies demonstrating that essential oil profiles vary according to phenological stage and metabolic demand (Grulova et al., 2015). The relatively low menthone and menthol levels in 'Cristal' further emphasize its divergent biosynthetic orientation compared with traditional menthol-type peppermint oils (Taherpour et al., 2017).

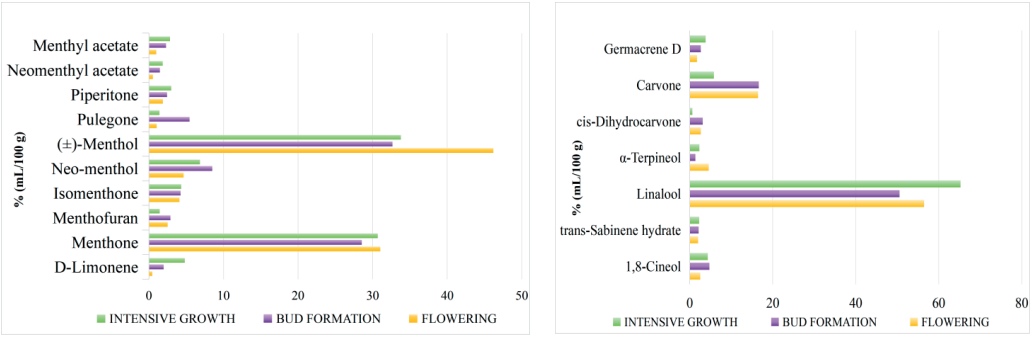

Figure 4. Main volatile compounds of a) 'Cordial' and b) 'Cristal'

Across both cultivars, early growth stages were characterized by a greater diversity of minor monoterpenes, including α-pinene, β-pinene, myrcene, and limonene, which declined toward flowering. This pattern reflects the preferential accumulation of monoterpenes in young, actively expanding leaves, consistent with observations in peppermint showing that leaves older than three weeks contribute less to essential oil biosynthesis (Grulova et al., 2015). A gradual reduction in certain sesquiterpenes, such as germacrene D and β-caryophyllene, at later stages aligns with evidence that environmental conditions and light quality can modulate farnesyl pyrophosphate FPP-derived biosynthetic pathways (Maffei et al., 1999). Additional differences were evident in the sesquiterpene fraction, with 'Cristal' containing aromadendrene, alloaromadendrene, and γ-cadinene, whereas 'Cordial' was characterized by (E)-β-farnesene, cubenol, globulol, viridiflorol, and T-muurolol. Although these compounds occurred in lower proportions than monoterpenes, their distinct distribution further

supports genotype-dependent regulation of terpenoid biosynthesis.

CONCLUSIONS

The present study demonstrates that both phenological stage and genotype significantly influence biomass production, essential oil composition, and antioxidant capacity in peppermint cultivars. Vegetative stages favored biomass accumulation, particularly in 'Cristal', whereas secondary metabolite synthesis was more pronounced during early growth and bud formation, especially in 'Cordial'. Antioxidant capacity closely followed phenolic content dynamics, confirming the strong relationship between total polyphenols and radical scavenging capacity.

Clear genotypic differences were observed: 'Cordial' exhibited superior essential oil quality and antioxidant potential, while 'Cristal' showed greater vegetative vigor and biomass productivity during intensive growth and bud formation. Environmental conditions further modulated these responses, enhancing essential oil accumulation but limiting regrowth capacity. These findings highlight the importance of selecting appropriate cultivars and harvest timing according to the intended production objective (biomass vs. phytochemical quality).

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