PLANT ACTIONS?
For a critical survey of agency in modular aneural organisms

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Abstract

Is it possible to attribute agency, goal-oriented behaviors, motor intentions, or "chemical actions" to plants? After an indispensable terminological and conceptual clarification – considering the presence of terms often used interchangeably, however connected – I report several criticisms and challenges associated with extending the concept of agency to the plant world. Following this, I discuss some premises required to address this topic, focusing on the unique structure and organization of plant bodies.

I then explore two examples of plant behavior: the first concerns ongoing research on the movements of climbing plants, and the second involves different levels of plant communication. Both examples provide evidence to consider the potential for plants to exhibit goal-directed, modular, and contextually adaptable behaviors. Further research into these capabilities could improve our understanding of non-muscular, less integrated, and more process-oriented forms of "action", thereby clarifying the influence of various processes and capacities involved.

Overall, studying plant characteristics and activities not only advances the discourse from a novel perspective but also facilitates updated conceptual distinctions, hypothesize new paths of research, and a deeper understanding of the systemic and relational aspects of plant interactions.

Keywords: Plant agency; Modular Organism; Goal-Directed Behavior; Climbing Plants; Plant Communication.

1. *Introduction*

Emerging research on plant abilities offers a valuable opportunity to explore the types of behavior exhibited by sessile organisms without nervous systems. This research provides a more critical and integrated perspective on the cognitive-behavioral capabilities of various organisms across the tree of life, both neural and non-neural, each within the scope of its per-

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ceptual-agentive strategies (Lyon 2006; Lyon *et al.* 2021). Such an analysis has the potential to reformulate traditional questions about behavior and to inspire new ones, starting from an unconventional point.

The relevance of this research is bidirectional: it has the potential to enrich current plant science while also generating profound impacts across diverse fields of contemporary philosophical analysis. This includes cognitive science (Calvo & Trewavas 2021), philosophy of mind (Bianchi & Castiello 2023a; 2023b), epistemology (Bianchi 2024a), and biosemiotics (Witzany 2016), all engaged in a dynamic interplay of reciprocal influence (Bianchi 2021; 2022).

In relation to the topics addressed in this article, I aim to explore whether and how a deeper analysis of plant characteristics and capacities can contribute to our understanding of different forms of agency, goal-directed behavior, and types of action. In brief, I investigate various ways these behaviors may transcend mere pre-programmed reactions to environmental stimuli.

2. *Origins and developments of the debate on organismal activities*

The presence of agency or goal-oriented behaviors has often been associated with a frequently criticized "teleological" explanation of living activity.

To begin the reflection, one might wonder why teleological explanations are widespread and often used, even in everyday life[1]. Quite simply, one could answer that the modes of thought that attribute goals or objectives[2] to the activities of organisms are often used because they have a fascination and a compelling descriptive power: once one gets used to using them, it is difficult to do without them (Godfrey-Smith 2009; Varella 2018). Conversely, if we ask ourselves what the relationship of this type of explanation is to genuinely scientific explanations, it can be seen their use as well as most of the references to an idea of "action", has not been without issues. This is because commonly, "actions" or "intentions", and in general, everything that pertains to the sphere of the agency has been traced back to "folk psychology", to something that has generally not been able to find a place within a scientifically informed vision of reality. As a result, many attempts have been made to negate agency, action, and its "finality", needing to be reduced to physical causality (Campbell 2015, p. 161).

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[1] E.g., if we see a person assembling ingredients in the kitchen, we imagine that she is preparing to eat, that is, her purpose is to prepare food (Heylighen 2023).

[2] Even in a non-finalistic sense, such as the existence of a predetermined goal to be achieved.

Building on Varella's (2018) detailed analysis, for the purposes of this discussion, it is relevant to focus on the challenges associated with what is broadly termed "teleological explanations" and the closely related issue of anthropomorphism, i.e., the prevalent tendency in biology to attribute human-like characteristics to the behaviors of living systems.

According to many authors, the widespread use of terms such as "meaning", "purpose", or "action" pertain to a use of language made for the human symbolic-linguistic level and would therefore be inadequate in other contexts (Jablonka & Ginsburg 2022), such as to explain the behavior of different organisms[3]. Of course, various research fields use different terms to describe teleological and anthropomorphizing attitudes. Some of these terms have a narrower scope, as they refer specifically to involuntary human behaviors, while others are broader, encompassing the attribution of intentions to any entity in the universe, including inanimate objects, as seen in some extreme forms of panpsychism.

Given awareness of these issues, should we then conclude that scientifically flawed teleological explanations, or the more moderate teleonomic positions, and the attribution of any form of agency – understanding that these are distinct cases – must be entirely dismissed when explaining the behaviors of living organisms?

Indeed, there are many cons, but also some pros and possible preventive measures to avoid the most serious misunderstandings. For instance, it is worth noting that the most radical, anti-telological, anti-teleonomic, or anti-anthropomorphizing approaches (e.g., certain forms of early behaviorism) have struggled to account for the evolution of communication processes arising from various ecological interactions among conspecifics and members of different species. These approaches have also faced challenges in acknowledging or have significantly downplayed the presence of cognitive abilities in other organisms, as well as emotions and forms of consciousness in non-human species. In short, by eliminating this level of behavioral analysis, perhaps "something would be lost" (Mahner & Bunge 1997, p. 367).

As stated by Varella (2018), a complete removal of teleological thinking does not appear to be entirely feasible or beneficial, given its capacity to establish connections and spark metaphorical reasoning that fosters innovation. A necessary preventive solution, after identifying the various biases

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[3] E.g., the author describes the phenomenon of "false positives", where there is an overactive tendency to detect agency in nonhuman organisms or even to attribute intentions to inanimate elements of the environment. This inclination is thought to have ancient biological roots, which, in our species, has been advantageous for evading predator attacks (Varella 2018).

that impact research, could involve a form of bio-education aimed at recognizing potential misunderstandings. For instance, this could be achieved by pairing each "why" question with a "how" question to offer a more balanced perspective between causal and functional factors (Hogan 2017).

Therefore, to avoid radical or naive outcomes, it's essential to understand in what sense and in which terms something is expressed. This is on a general level.

2.1 *Which positions do not seem to work: the problems of internalism*

I attempt to extend the discussion on agency to aneural organisms (which include not only plants but potentially fungi and unicellular organisms as well) and consider which approach might be most appropriate. It may be easier to identify which perspectives are unlikely to be effective.

Historically, for instance, a series of internalistic assumptions about goal-oriented or goal-directed behaviors have posed challenges. Examples that fall under this broad category include *élan vital* (Bergson 1907), entelechy, vitalism (Walsh 2018), and appeals to conscious intentionality[4].

Similarly, the concept of "mental action" (Metzinger 2017) is not particularly helpful here. Some authors argued that even when used to explain human agency, "mental action", when conceived from a disembodied perspective, is problematic, given that every level of interaction can be traced back to the embodied nature of the organism and its relationship with the environment (Levy 2019)[5].

Other difficult-to-defend hypotheses include those based on the existence of biographical identity models or the supposed presence of beliefs, desires, or "mental representations" (in the fullest sense). These concepts have been variously defined in common-sense psychology and cognitivism (for a detailed discussion of different conceptions of "representation", see Bianchi & Castiello (2023a; 2023b). However, a different case is the explanation of dynamic, non-conceptual motor representa-

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[4] The reference here is to forms of reflexive self-consciousness: consciousness understood not simply as a form of "awareness", or the ability to distinguish between self and non-self, genetically related organisms, and the significant elements of one's environment. In these terms, such forms of awareness are now increasingly being recognized even in plants (Segundo-Ortin & Calvo 2022; Gilroy & Trewavas 2023).

[5] As Levy (2019) pointed out, it does not make much sense to separate mental actions from bodily actions, since the body is always involved. Instead, it would be more meaningful to explore the distinction between covert and overt acts, particularly in relation to the issue of third-person observability.

tions used to guide, control, and anticipate movements in order to achieve goals (Pacherie 2011).

2.2 *More inclusive approaches*

Shall we now consider some perspectives that might help frame goal-directedness and goal-oriented behaviors across a broader range of systems, including organisms without a nervous system, such as plants, and describe "directionality" in a less mentalistic and more operational manner? Such an approach would be rooted in a broader explanatory framework that aligns more closely with mathematical and physical explanations.

For instance, without delving deeply into theoretical specifics, Heylighen (2023) explained the meaning and origin of goal-directedness based on the theory of dynamical systems regarding the self-organization of living systems to achieve different goals (starting with the broadest one of all, i.e. the need to survive, an aspect that would distinguish living systems from non-living ones), even in the more basic phases of organic organization.

Another attempt to explain goal-directedness, in this case also in non-living systems (and even in evolutionary processes), is that of McShea (2023) through the field theory[6], where a field[7] can be described as the set of external conditions that allow a system to behave in a targeted, persistent and plastic way (Lee & McShea 2020), distinguishing differently salient elements in the environment.

In this introductory section, another issue that must be addressed is the "cultural-epistemological-terminological" problem, a set of deeply interwoven aspects.

There seems to be a cultural variation in the tendency to attribute agency or goal-directed behaviors to organisms, depending on how one conceptualizes this aspect of behavior.

For instance, Medin and Garcia (2017) highlighted differences in how plant agency is perceived – a useful case study because it is counterintuitive – between the Indigenous Ngöbe people in Panama and U.S. university

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[6] E.g., McShea (2023) described how a sea turtle can return to the beach where it was born by using the Earth's magnetic field for navigation (Lohmann & Lohmann 2019). This behavior is both persistent (turtles that are pushed off course by ocean currents can adjust their trajectory and return to their birthplace) and plastic (as turtles can start from various locations, even hundreds of kilometers away, yet still navigate back to the same beach using the Earth's magnetic field).

[7] An approach that has faced criticism for attributing the explanation of goal-directedness primarily to external factors (Heylighen 2023).

students. The Ngöbe were more inclined to attribute intentional actions and complex communication abilities to plants, likely due to their daily interactions with diverse plant ecologies. In contrast, U.S. students tended to view agency as a psychological property, associated with unobservable mental states that drive actions, rather than something rooted in communicative and interactive abilities. This suggests, in summary, that cultural models are based on two distinct conceptual frameworks of action rather than variations of a single universal model.

3. *Terminological and conceptual clarification*

I will now clarify the connections between various terms and related concepts – such as "agent", "agency", "action", "intention", "goal-directedness", or "goal-directed behavior" – that are often used interchangeably or in relation to one another in literature discussing the cognitive-behavioral capacities of different species. These terms frequently overlap in meaning, creating areas of ambiguity.

The discussion begins with the term "agent". If the purpose is to speak in the most inclusive way possible and in the broadest possible sense, before addressing the specific characteristics of various species and to extend the analysis prudently to plants, we must avoid referring to concepts such as "will" (Rigato 2016) or "free will", which are inherently problematic, even when applied solely to human capacities. Nor will the reference include epistemological aspects tied to propositional or conceptual levels.

From a more general perspective, one could describe an "agent" as distinct from a "patient", although an agent can become a patient depending on external circumstances, and vice versa (Alvarez & Hyman 1998). Additionally, the notion of an agent is often associated with "making things happen" rather than events merely "happening" (e.g., Campbell 2015, p. 162; Godfrey-Smith 2021, p. 74). In brief, this implies the capacity to influence the surrounding environment. Here, "environment" refers to both abiotic and biotic dimensions, which are intricately linked. The biotic dimension includes other organisms, suggesting that an agent also can affect the behavior of other living beings.

The idea of an agent has also been described as more than just the mereological sum of its individual parts (Rigato 2016). In other words, it assumes the existence of a goal-oriented organization that possesses a certain degree of functional unity (potentially at the level of the organism, a question that becomes particularly relevant when considering plants). Additionally, on a general level, biological agents are often seen as capable of proactive (anticipatory) and relatively flexible behaviors (Longo *et al.* 2015; Okasha 2018; Kiverstein & Sims 2021; Jablonka & Ginsburg 2022).

Shifting focus from the agent itself to the concept of "agency", it is possible to discuss this in terms of activity. According to Haggard and Chambon (2012), a fundamental question concerns the sense of agency from the perspective of personal experience in human beings. This sense of agency can be described as the feeling of being in control of one's actions (or experiencing one's own actions, as discussed by Searle 1980). The significance of this experience becomes evident in certain psychiatric disorders, where individuals may feel that an external agent is acting on their behalf or instead of them. Similarly, agency has been defined as the conscious experience of effectively selecting an action. Interestingly, the sense of agency has also been described as a form of confabulation, a retrospective explanation that arises after the fact to justify choices that have already been made (Johansson *et al.* 2005).

While these explanations are compelling, what matters most in this discussion is the more general level of reasoning. From this perspective, agency implies the existence of an agent (as previously defined) that causes an event or initiates a response or behavior. Furthermore, the concept of agency is frequently associated with intention or intentionality, which can have varying interpretations (Alvarez & Hyman 1998).

For instance, "intentionality" has been identified as a defining feature of mental phenomena, described as the content of psychic experiences (Brentano 1874), generally in the context of human cognition. More specifically, it refers to intentional states, which are always directed toward or concerned with objects or states of affairs in the world and consist of symbolic content expressed in a psychological modality.

The concept also encompasses "intentions" that precede actions and "intentions" in action (Searle 1980), often linked to the control of actions or decision-making capacities underlying intentional behaviors. For our purposes, greater emphasis is placed on more inclusive approaches that recognize forms of pre-conceptual sensorimotor intentionality, which underlie the maintenance of an integrated neuromotor self (Delafield-Butt & Gangopadhyay 2013).

At this point, one might ask whether it is possible to quantify or mathematically explain intentions. One approach, informed by ongoing research on kinematics, aims to understand motor intentions (Bonini, Ferrari, & Fogassi 2013). Even simple motor processes are influenced by future goals, prior knowledge, and contextual factors (Jeannerod 1988). According to some scholars, the “how” of an action is in some way shaped by the “why” behind it (Ansuini *et al.* 2014). For example, the way an object is grasped depends not only on its physical characteristics but also on the acting intentions (Becchio *et al.* 2010).

We might further ask whether motor intentions have been and are currently being studied in the field of comparative cognition in animals. Additionally, it is worth noting that other animals – each utilizing their dominant and developed sensory-perceptual capacities – are capable of detecting variations in movement and, more broadly, in the behavior of conspecifics. This refers to their ability to observe the actions of other organisms and respond accordingly (Emery & Clayton 2009). Does this involve appropriately “interpreting” the intentions of others (partially visible through the modulation of behavior) in a given context? (Fogassi *et al.* 2005). And when it comes to plants, are we ready to tackle this challenge? This question will be addressed later.

Regarding the concept of “action”, it has been widely and diversely reflected upon within various philosophical traditions, including what has been termed the philosophy of action (Delafield-Butt & Gangopadhyay 2013). While I cannot here cover every philosophical conception developed around action, it is important to recognize the significance and pervasiveness of this concept, especially as emphasized by Pragmatism. As Kilpinen (2008) has noted, Pragmatism, as a post-Darwinian philosophy, broadened the conception of action and critically engaged with the “mind-first” problem. This refers to the dualistic notion that action must stem from a preceding mental or rational activity, which, among other issues, has created a perceived divide between human and other animal actions. In humans, actions – particularly social ones, given our eco-socio-cultural niche of interaction – are essential for knowledge and problem-solving, including communication and general survival. According to the conventional view, an action is typically described as an intentional behavior (Rigato 2016). By examining action at a more fundamental level, as we did with previous concepts, we can at least say that an action differs from a mere movement. For instance, if someone were to raise my arm, that movement would not constitute *my* action (Morabito 2020, p. 14; Searle 1980).

While avoiding rigid categorization, we can still distinguish between different types of actions in a meaningful way. We might classify actions into categories such as “reflexive”, “epistemic-exploratory”, “muscular-motor”, and “chemical” actions. These distinctions become particularly relevant in discussing plant agency, where the goal is to conceptualize plant behaviors not as simple, inflexible reactions to the environment. In fact, actions are often considered one of the characteristics that differentiate living organisms from non-living ones. As Campbell (2015, pp. 161-190) argues, even “minimal” or simple actions, when considered in the broadest sense, include characteristics such as the possibility of error (where outcomes matter); functional self-organization of the system to act; varying impacts on the system (beneficial, neutral, or harmful) depending on its goals; and the ability to alter a state of affairs (e.g., the life context of other organisms).

Finally, connected to these concepts is the idea of goal-oriented behavior or, more broadly, goal-directedness. In a general sense, a goal can be understood as something that directs the cohesive behavior of a system (Jablonka & Ginsburg 2022). All self-organizing systems exhibit goal-oriented behavior and possess some capacity for decision-making. Without this capacity, entirely pre-programmed organisms would be too fragile to survive. From a philosophical perspective, as McShea (2023) pointed out, the focus should not be on finding an ultimate definition or specifying the necessary and sufficient conditions for goal-directedness. Instead, it is more productive to examine varying degrees of “persistence” and “plasticity” across different systems. Persistence refers to a system’s ability to reach its goal despite external disturbances that may alter its course, while plasticity describes a system’s capacity to achieve the same goal even when starting from different initial points or conditions.[8] When comparing the characteristics and abilities of various systems, scientists face significant challenges in designing experimental setups that can meaningfully compare different species. These challenges stem from the fact that species vary greatly in their structural and functional organization, have distinct needs, and inhabit diverse ecological niches.

4. *Examining the plant case*

I would now like to delve into the characteristics and capacities of plants and the possibility of attributing some agentive capacity to them.

I begin with some critical reflections, particularly those presented in a stimulating paper by Arnellos and Moreno (2015). The authors discussed the difficulty of framing the concept of agency in plants, noting that agency has traditionally been associated with the animal kingdom,

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[8] As Lee and McShea (2020) illustrated, persistence can be seen when a student walking toward the classroom pauses to greet a friend but then resumes their path toward the classroom. An example of plasticity is when a student heads to the homeroom, whether starting from the dining hall or the dormitory.

except in a basic sense that applies to all self-organized living systems. According to Arnellos and Moreno, full-fledged agency, in the traditional sense, is limited to multicellular organisms equipped with a nervous system. The nervous system serves as the integrative center for the acting self and the sensorimotor cycles that achieve constitutive-interactive closure.

By this standard, plants would not qualify as full agents because they do not clearly separate constitutive processes (those fundamental to metabolic cycles essential for survival) from interactive processes (which facilitate environmental interactions). For instance, growth processes are intricately involved in many plant behaviors. Moreover, many plant responses are localized. A well-known example is the Venus flytrap (*Dionaea muscipula*), whose trap-like leaves can catch insects and operate independently of the rest of the plant.

Does attributing agency, or even a minimal capacity for "action", to plants constitute a categorical error? Is it a trivialization of the capacity to act (Bianchi 2024b)? One might argue that just because something is less complex or fundamentally different, it does not make it any less interesting. The complexity of plants may lie at a different level, for example, in their sophisticated abilities to synthesize, emit, and recognize chemical compounds.

Therefore, a promising direction for future research, aligned with genuinely comparative approaches to behavior, would be to examine diverse sensory-cognitive specializations. Instead of assessing a specific behavioral trait along a singular scale (De Waal 2016) or relying on a single evaluative criterion (Nick 2021), we should embrace the diversity of behavioral phenomena across different forms of life.

4.1 *"Individuality" in divisible organisms: the problem of integration and coordinated responses*

Therefore, enriched by these considerations, a necessary premise is related to plants' bodies different structures and functional organization. The challenge of attributing some form of "individuality" to plants – enabling the integration of various types of information and the provision of relatively coordinated responses to the myriad challenges posed by life – stems from their characteristic "modularity". This refers to the fact that plants are "divisible" organisms, potentially dissectable (though it is worth noting that this varies significantly across species). For example, when attacked by herbivores, plants can lose a substantial portion of their biomass without perishing (Mancuso & Viola 2015). In sum, plant modularity underpins the debate regarding their supposed lack of individuality, consciousness, and overall behavioral capacity.

Since Firn's skepticism in 2004, Trewavas (2004) has countered by arguing that plants must develop all essential organs to survive[9] and are indeed capable of relatively coordinated responses. A growing area of research in recent years has focused on plant electrical potentials (Vodeneev *et al.* 2015) and the comprehensive capacity for systemic communication of chemical signals within the phloem, the vascular system responsible for the translocation of photosynthates (Lucas *et al.* 2013; Segundo-Ortin & Calvo 2023).

Given these traits, it is not appropriate to discuss "subjectivity" in plants, as the term often relates to characteristics specific to our species, such as personal identity or moral responsibility in action. Instead, a more fitting concept may be "agency", understood in the broader and more inclusive sense mentioned earlier. Even if "individuality" does not entirely apply to plants, one could at least speak of a unique "history" or individual "life path", characteristic of every living being, including plants (Bianchi 2024b).

An alternative approach proposed for describing plants is to refer to them as "pre-individuals" (e.g., Faucher 2014). However, this characterization risks implying a deficiency compared to the animal paradigm (Baker 2017).

4.2 *What is meant by "individual"?*

One of the most compelling aspects of this reflection is that reasoning about the characteristics of plants invites us to reconsider what we mean by "individual" (Baluška & Mancuso 2021). The concept of "individuality" has been interpreted in various ways, such as the unique way organisms respond to specific chemicals (Williams 1956; Trewavas 2003). Alternatively, individuality has been linked to genomic uniformity, where each organism has its distinct DNA. However, a more realistic perspective would emphasize the idea of "sharing" (Gagliasso 2019), since multicellular organisms are not composed solely of their own cells but host billions of endosymbionts, such as bacterial cells, each with its own DNA (Pievani 2017, p. 118). Another approach to understanding "individual-

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[9] E.g., a single leaf or root, without the other functional components and not placed in the right context, would perish (cfr. Trewavas 2014).

ity" pertains to the agentive-functional aspect, referring to the ability of systems to act coherently in certain contexts to achieve their goals.

Reflecting on what a plant is, and how it interacts with its environment through its unique structure and behavioral strategies, can enrich and challenge traditional notions of individuality. This reflection can lead to rethinking the scope and boundaries of the concept. Consider, for instance, clonal plants whose roots spread across many kilometers, adapting to diverse local conditions. At an ecological and relational level, one could also think of the emergent properties found in a forest, which are not attributable to a single tree (Latzel, Rendina González & Rosenthal 2016).

Given these complexities, should we abandon the concept of "individual" entirely? Perhaps a more productive approach would be to embrace the hybrid nature of plant behavior, which lies between modularity and some degree of information organization and coordination (e.g, at the level of systemic electrical signaling). This could lead to a concept of "modular individuality", a term that, while almost oxymoronic, captures the unique features of plants (Bianchi 2024b).

4.3 *The concept of agency applied to plants*

I now consider some promising approaches to applying the concept of agency to the plant world. It is important to acknowledge that this endeavor, while potentially fruitful, also carries the risk of failure (initial risks are necessary for exploration). This approach does not seek to undermine or oversimplify the complexity of actions facilitated by the nervous system. Instead, it aims to explore a form of action that, although non-muscular, still involves movement (as observed in climbing plants) and chemical processes (such as plant communication). This perspective may broaden our understanding of the diverse strategies plants use to achieve survival and influence their environment (Bianchi *et al*., 2025a).

It's worth noting that the concept of agency has only recently been extended to the study of non-human behaviors and remains somewhat ambiguous. However, it is precisely this vagueness that could endow the concept with significant heuristic potential (Bianchi 2024b).

As emerged from the considerations of Segundo-Ortin (2020) in the ongoing extension of the concept of agency to potentially include plants, one path to avoid is relying on the "standard theory" of agency, which is based on propositional-conceptual or representational frameworks for studying actions. A more transversal proposal derives from the conceptions of agency of scholars belonging to the ecological and enactivist school of thought. While these perspectives differ from one another (a distinction that cannot be fully explored here), they both stem from post-cognitive theories that emphasize the dynamic relationship between organisms and their environment.

For instance, Barandiaran *et al.* (2009) proposed that a system exhibits agency if it satisfies three criteria: (i) distinguishing itself from its environment to interact with it, (ii) modulating its interaction with the environment by initiating actions or resisting external influences, and (iii) pursuing goals through actions that can succeed or fail relative to the intended purpose.

In light of these extensions and insights, Gilroy and Trewavas (2023) have recently outlined ways to describe certain goal-directed activities in plants, which are primarily linked to individual phenotypic plasticity during development and demonstrate how plants adapt to their surroundings to achieve specific goals.

5. *The movements of climbing plants*

The groundwork seems ready to explore in more detailed two examples of plant capacities: the movement of climbing plants and plant communication. These cases could, in future research, provide evidence supporting the presence of motor intentions, goal-oriented behaviors, or forms of "chemical" action in these organisms.

I start by examining movement. At a general level, it is necessary to remember that plants are indeed capable of movement. Although, with some exceptions, they cannot engage in "locomotion" as animals do, meaning they cannot move from point A to point B (Calvo & Keijzer 2011).

Plant movements are significant as they enable environmental exploration, the search for light above ground, and root-level foraging (de Kroon *et al.* 2009; Chaill *et al.* 2010). While plants lack contractile units like muscles, they move by curving their organs. Growth-driven movements are mediated by phytohormones such as auxins, and rapid movements in some species (e.g., *Mimosa pudica* or certain carnivorous plants) result from turgor variations caused by differences in osmotic pressure between the vacuole and the cytosol. Movements can be "active", involving metabolic energy, or "passive," such as hygroscopic or desiccation-based movements, which depend on changes in environmental conditions like humidity.

Different types of movements include nutations, which are spontaneous movements of plant organs, and tropisms, which are directed movements toward stimuli that attract plants (e.g., phototropism for light, gravitropism for, etc.) (Castiello 2019).

Focusing on the movements of climbing plants, we have known since the groundbreaking research of Charles and Francis Darwin, detailed in *The Movements and Habits of Climbing Plants* (1875) and *The Power of Movement in Plants* (1880), that plants exhibit selective abilities. They can reject supports that are unsuitable in size or material (e.g., supports that are too large, too smooth, or difficult to climb) and can "plan" their movements based on the type of goal to be achieved. These behaviors suggest that plant movements may be ecologically motivated and controlled (Bianchi 2025).

This fascinating line of inquiry continues today at the *Mind(the)Plant Laboratory* at the University of Padua. The lab's main goal is to understand how plants modulate their behaviors in response to various stimuli and different contexts.[10]

More specifically, this research utilized three-dimensional kinematic analyses to study the circumnutation motion of *Pisum sativum L.* through time-lapse observations. The study revealed the plant's ability to adjust the opening of its tendrils and modify the speed at which it approached stimuli (wooden supports). Plant data were then analyzed from a comparative perspective, drawing parallels with established research on animal behaviors, such as the Speed-Accuracy Trade-Off, which links the accuracy of an action to the speed of movement (Fitts 1954). Observations showed variations in the number of sub-movements produced, depending on stimulus characteristics and environmental context (Ceccarini *et al.* 2020).

The research investigated plants both individually (Guerra *et al.* 2019) and in "social" contexts (Bonato *et al.* 2023), deriving different circumnutation trajectories using motion tracking techniques. A lingering question remains: What sensory abilities enable plants to perform these actions, and how do they accomplish them? Ongoing research suggests that plants likely possess a multisensory capability, involving the integration of multiple senses and abilities (Bianchi *et al*. 2025a).

Anyway, how does this relate to the main topic we are discussing? As previously mentioned, kinematic studies of plant movement allow us to quantify variations in movement type and speed in response to different

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[10] Future research will need to investigate plant behavior in more natural ecological contexts; for now, it is necessary to continue collect data to compare them subsequently.

stimuli and interaction contexts. This raises the question: Can we speak of motor intentions in plants? Is there any intentional component observable in how plants modulate their movements?

In this context, "motor intentions" in plant behaviors are considered as goal-directed activities that vary based on environmental cues. Do plants exert any form of "behavioral" or "ecological" control over these simple basic actions? Wang *et al.* (2021) posed several intriguing questions, such as: To what extent, and in what ways, can plants intentionally plan their movements? Can these aneural organisms "interpret" the collaborative or competitive intentions of other organisms, and if so, how? Do social interactions among plants involve processes common to both plants and other life systems, or are there mechanisms unique to plants?

This leads to the consideration of theoretical models suitable for studying such behaviors. If the target remains constant, are variations in movement attributable to the action's goal or intention? This might depend on the variety of "goals" a climbing plant has, beyond the primary objective of gaining access to light and structural support. It is already evident that movements toward a goal, like a wooden support, vary depending on the stimulus's characteristics and the surrounding context, such as the presence of other plants, whether of the same or different species.

We are still searching for the most effective ways to explain all these interactions.

Explaining these behaviors through the concept of affordance appears promising.[11] This may be one way, although it may not necessarily be the only way, to analyze the relationship between ecologically coupled systems, such as plant-pole or plant-plant interactions, and their environment. It suggests that plants can detect ecologically relevant traits and respond with appropriate movements (Michaels & Carello 1981; Segundo-Ortin 2020).

6. *The communication behavior of plants*

The second example, which deserves exploration, might shed light on the ability of plants to respond in ways that are neither purely passive nor entirely pre-programmed for environmental conditions, suggesting a capacity to exhibit behaviors that can be described as somewhat goal-orient-

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[11] The concept of affordance is not a substitute for representation, but a relational concept to indicate the possibilities of perception-action that emerge in organism-environment interactions (Bianchi 2024a).

ed. This is particularly evident in ongoing research into the sophisticated communication behaviors of plants, which are primarily, though not exclusively, of chemical nature (Karban 2017).

Taking a cautious approach, some researchers argued that it is more appropriate to refer to this as "signaling" rather than genuine "communication", especially when signals occur between different parts of the same plant rather than between separate organisms. However, the focus of current research is precisely on identifying whether. Plants can actively regulate the emission of these signals by selecting the type of substance and modulating the amount (Chamovitz 2012; Raguso & Kessler 2017).

If we were to consider this in terms of "communication", in what sense would it apply? The reference point would be comparative research on biocommunication, encompassing all organisms across the evolutionary tree, each with different organizational structures and communication strategies (Witzany & Baluška 2012; Bonato *et al.* 2021).

Plants have sophisticated chemical-electrical signaling capabilities within their bodies (Orians & Jones 2001), external signaling mechanisms such as the emission of volatile organic compounds (VOCs) into the air and the release of root exudates (secondary metabolites) into the soil (Semchenko *et al.* 2014). They also engage in long-distance signaling facilitated by mycorrhizal symbiosis (Simard *et al.* 2012). The vast array of signals is linked to the numerous interactions plants have with members of the same or different species, as well as with organisms from other kingdoms (Sharifi & Ryu 2020).

The primary reasons for VOCs release include attracting pollinators, defending against herbivores and pathogens, and adapting to various environmental stressors (War *et al.* 2012; Baldwin *et al.* 2006). Root exudate signaling plays crucial roles in kin recognition (distinguishing genetically related organisms to minimize competition), facilitating symbiotic relationships, and influencing the root microbiome and surrounding soil microbial communities (Parise, Gagliano & Souza 2020). Plant communication also involves variations in the shapes and colors of flowers and leaves, further adding to their complex signaling repertoire (Nansen 2017).

One interesting aspect is that plant communication is influenced by the dosage of substances emitted, the interaction context, and the combinatorial nature of the messages (Peñuelas, Llusià & Estiarte 1995; Witzany 2008).[12] Because of these attributes, some researchers have even suggested

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[12] E.g., some substances emitted in small quantities are attractants, and in large quantities are/become repellents (Harborne 1991).

that plants possess a "manipulative" ability, particularly in their interactions with insects, in relation to reproduction (Mancuso & Viola 2015).

Regardless of whether we refer to these abilities as genuine "communication" or something else, what remains significant is the plants' capacity to modulate their emissions, leave chemical traces, and influence their surroundings through targeted responses. These behaviors can have substantial impacts on other organisms (Bianchi 2021; 2022), and overall achieve their survival "goals".

7. *Further insights and perspectives*

Future analyses will shed light on and clarify goal-oriented behaviors, the potential presence of intentional aspects, and what could be broadly characterized as a form of agency. These studies will simultaneously examine multiple expressions of plant behavior, including movement, the emission of VOCs, electrical signaling, gene expression during specific activities, and transcriptomics to study RNAs, including those translated into proteins as well as non-coding RNAs involved in regulation and cellular processes.

More broadly, incorporating plants into research on agency, goal-directed behaviors, and motor intentionality could fundamentally challenge our conventional understanding of many concepts and categories commonly used to explain cognitive-behavioral abilities. Given the unique structure and organization of plant bodies – and the often counterintuitive nature of these ideas – this approach offers a different perspective. It has the potential to advance discussions in cognition and comparative psychology, refine our conceptual distinctions, propose new research pathways, and question long-held assumptions (Bianchi *et al*. 2025b).

Moreover, this research will deepen our understanding of the systemic and relational aspects of interaction. It will provide insights into non-muscular, less integrated, and more process-based forms of "action", thereby clarifying how different processes and capacities influence each other beyond the porous boundaries of plant bodies and into the surrounding environment. This could also lead to practical outcomes, such as the design of new set-ups and the development of experimental procedures and testing methods.

We don't have all the answers yet. Many questions and open issues remain, otherwise, we wouldn't call it "research".

References

Alvarez, M., Hyman, J.
1998 Agents and their Actions. *Philosophy*, *73*(2), 219-245.

Ansuini, C., Cavallo, A., Bertone, C., Becchio, C.
2014 The visible face of intention: why kinematics matters. *Frontiers in psychology*, 5, 98276.

Arnellos, A., Moreno, A.
2015 Multicellular agency: an organizational view. *Biology & Philosophy*, 30, 333-357.

Baker, E.N.
2017 The intelligence of plants and the problem of language: a Wittgensteinian approach, in Gagliano M., Ryan J.C., Vieira P. (a cura di), *The Language of Plants: Science,Philosophy, Literature*, pp. 136-154. University of Minnesota Press, Minneapolis.

Baldwin, I.T., Halitschke, R., Paschold, A. *et al.*
2006 Volatile signaling in plant-plant interactions "talking trees" in the genomics era. *Science*, 311(5762), 812-815.

Baluška, F., Mancuso, S.
2021 Individuality, Self and sociality of vascular plants. *Philosophical Transactions of the Royal Society B*, 376 (1821), 20190760.

Barandiaran X. E., Di Paolo E., Rohde M.
2009 Defining agency: individuality, normativity, asymmetry, and spatio-temporality in action. *Adaptive Behavior*, 17, 5, 367-386.

Becchio, C., Sartori, L., Castiello, U.
2010 Toward you: The social side of actions. *Current Directions in Psychological Science*, 19(3), 183-188.

Bergson, H.
1907 *L'évolution créatrice*, Librairie *Félix* alcan, Paris.

Bianchi, M.
2021 *La vita ramificata. Cognizione e comportamento nelle piante fra scienza e filosofia*, Mimesis, Milano-Udine.
2022 Networks and ramifications: relational perspectives in plant cognition. *Rivista Internazionale di Filosofia e Psicologia*, 13, 2, pp. 157-168.

2024a Plant cognition. Challenges and horizons in philosophical reflection. *Paradigmi*, 1, pp. 21-46.

2024b *Le Implicazioni Filosofiche della Cognizione Vegetale*, Doctoral thesis, University of Rome “La Sapienza”.

2025 *Oltre il Mondo Animale: i Darwin e la Botanica*. In Gagliasso, E., Pollo, S. & Severini, E. (a cura di), Origine e attualità dell’Origine dell’uomo. Scienza, Etica, Letteratura (pp. 33-54). Edizioni ETS.

Bianchi, M., Castiello, U.

2023a Il concetto di rappresentazione nelle scienze cognitive classiche e post-classiche: la sfida della cognizione vegetale. *Giornale Italiano di Psicologia*, 50, 2, pp. 349-385.

2023b Riflessioni corali nell’analisi interdisciplinare sul concetto di rappresentazione nella cognizione vegetale. *Giornale Italiano di Psicologia*, 50, 2, pp. 419-452.

Bonato, B., Peressotti, F., Guerra, S., Wang, Q., Castiello, U.

2021 Cracking the code: a comparative approach to plant communication. *Communicative & Integrative Biology*, 14, 1, pp. 176-185.

Bonato, B., Simonetti, V., Bulgheroni, M., Wang, Q., Guerra, S., Quaggiotti, S., Castiello, U.

2023 Evidence of motor intentions in plants: A kinematical study. *Journal of Comparative Psychology*.

Bonini, L., Ferrari, P.F., Fogassi, L.

2013 Neurophysiological bases underlying the organization of intentional actions and the understanding of others’ intention. *Consciousness and cognition*, 22(3), pp. 1095-1104.

Brentano, F.

1874 *Psychologie vom empirischen Standpunkte* (Psychology from an empirical standpoint), Routledge and Kegan Paul Humanities Press, London.

Calvo, P., Keijzer, F.

2011 Plants: Adaptive Behavior, Root Brains and Minimal Cognition. *Adaptive Behavior*, 19, 3, pp. 155-171.

Calvo, P., Trewavas, A.

2021 Cognition and intelligence of green plants. Information for animal scientists. *Biochemical and Biophysical Research Communications*, 564, pp. 78-85.

Campbell, R.

2015 *The Metaphysics of Emergence*, Palgrave Macmillan, London.

Castiello, U.
2019 *La mente delle piante. Introduzione alla psicologia vegetale*, il Mulino, Bologna.

Ceccarini, F., Guerra, S., Peressotti, A., Peressotti, F., Bulgheroni, M., Baccinelli, W., Castiello, U.
2020 Speed-accuracy trade-off in plants. *Psychonomic Bulletin & Review*, 27, pp. 966-973.

Ceccarini, F., Guerra, S., Peressotti, A., Peressotti, F., Bulgheroni, M., Baccinelli, W., Castiello, U.
2021 On-line control of movement in plants. *Biochemical and Biophysical Research Communications*, 564, pp. 86-91.

Cahill JR, J.F., Mcnickle, G.G., Haag, J.J., Lamb, E.G., Nyanumba, S.M., ST. Clair, C.C.
2010 Plants integrate information about nutrients and neighbors. *Science*, 328(5986), pp. 1657-1657.

Chamovitz, D.
2013 *Quel che una pianta sa. Guida ai sensi nel mondo vegetale*, Raffaello Cortina, Milano.

Csibra, G., Gergely, G.
2007 'Obsessed with goals': Functions and mechanisms of teleological interpretation of actions in humans. *Acta psychologica*, 124(1), pp. 60-78.

Darwin, C.R.
1875 *The Movements and Habits of Climbing Plants*, John Murray, London.
1880 *The Power of Movement in Plants*, John Murray, London.

De Kroon, H., Visser, E.J., Huber, H., Mommer, L., Hutchings, M.J.
2009 A modular concept of plant foraging behaviour: the interplay between local responses and systemic control. *Plant, Cell & Environment*, 32(6), pp. 704-712.

De Waal, F.B.
2016 *Are we smart enough to know how smart animals are,* WW Norton & Company, New York.

Delafield-Butt, J.T., Gangopadhyay, N.
2013 Sensorimotor intentionality: The origins of intentionality in prospective agent action. *Developmental Review*, 33(4), pp. 399-425.

Emery, N.J., Clayton, N. S.
2009 Comparative social cognition. *Annual review of Psychology*, 60, pp. 87-113.

Faucher, K.
2014 Phytosemiotics revisited: botanical behaviour and sign transduction. *Semiotica*, 202, pp. 673-688.

Firn, R.
2004 Plant intelligence: an alternative point of view. *Annals of* Botany, 93(4), pp. 345-351.

Fitts, P.M.
1954 The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47(6), 381.

Fogassi, L., Ferrari, P.F., Gesierich, B., Rozzi, S., Chersi, F., Rizzolatti, G.
2005 Parietal lobe: from action organization to intention understanding. *Science*, 308(5722), pp. 662-667.

Gagliasso, E.
2019 Condividui in evoluzione: quale filosofia?, in M. Monti, C. Redi (a cura di), *CON-dividuo. Cellule e Genomi*, pp. 81-96. Collegio Ghislieri, Pavia.

Gilroy, S., Trewavas, T.
2023 Agency, teleonomy and signal transduction in plant systems. *Biological Journal of the Linnean Society*, 139(4), pp. 514-529.

Godfrey-Smith, P.
2009 *Darwinian Populations and Natural Selection*, Oxford University Press, New York.
2021 *Metazoa. Gli animali e la nascita della mente*, Adelphi, Milano.

Haggard, P., Chambon, V.
2012 Sense of agency. *Current Biology*, 22(10), R390-R392.

Harborne, J.B.
1991 The chemical basis of plant defense. *Plant defenses against mammalian herbivory*, 45.

Heylighen, F.
2023 The meaning and origin of goal-directedness: a dynamical systems perspective. *Biological Journal of the Linnean Society*, 139(4), pp. 370-387.

Hogan, J.A.
2017 *The Study of Behavior: Organization, Methods, and Principles*, Cambridge University, Cambridge.

Jablonka, E., Ginsburg, S.
2022 Learning and the evolution of conscious agents. *Biosemiotics*, 15(3), pp. 401-437.

Jeannerod, M.
1988 *The neural and behavioural organization of goal-directed movements*, Clarendon Press-Oxford University Press, Oxford.

Johansson, P., Hall, L., Sikstrom, S., Olsson, A.
2005 Failure to detect mismatches between intention and outcome in a simple decision task. *Science*, 310(5745), pp. 116-119.

Karban, R.
2017 Plant communication increases heterogeneity in plant phenotypes and herbivore movement. *Functional Ecology*, 31(5), pp. 990-991.

Kelemen, D.
2012 Teleological minds. *Evolution challenges: integrating research and practice in teaching and learning about evolution*, *66.*

Kilpinen, E.
2008 Pragmatism as a Philosophy of Action. *First Nordic Pragmatism Conference, Helsinki, Finland*.

Kiverstein, J., Sims, M.
2021 Is free-energy minimisation the mark of the cognitive? *Biology & Philosophy*, 36(2), 25.

Latzel, V., Rendina González, A.P., Rosenthal, J.
2016 Epigenetic memory as a basis for intelligent behaviour in clonal plants. *Frontiers in Plant Science*, 7, 1354.

Lee, J.G., Mcshea, D.W.
2020 Operationalizing goal directedness: an empirical route to advancing a philosophical discussion. *Philosophy, Theory, and Practice in Biology*, 12(005).

Levy, Y.
2019 What is 'mental action'? *Philosophical Psychology*, 32(6), pp. 969-991.

Lohmann, K.J., Lohmann, C.M.
2019 There and back again: natal homing by magnetic navigation in sea turtles and salmon. *Journal of Experimental Biology*, 222(Suppl_1), jeb184077.

Longo, G., Montévil, M., Sonnenschein, C. Soto, A.M.
2015 In search of principles for a theory of organisms. *Journal of Biosciences,* 40(5), pp. 955-968.

Lucas, W.J., Groover, A., Lichtenberger, R., Furuta, K., Yadav, S.R., Helariutta, Y., KACHROO, P.
2013 The plant vascular system: evolution, development and functions. *Journal of integrative plant biology*, 55(4), pp. 294-388.

Lyon, P.
2006 The biogenic approach to cognition. *Cognitive Processing*, 7, pp. 11-29.

Lyon, P., Keijzer, F., Arendt, D., Levin, M.
2021 Reframing cognition: getting down to biological basics. *Philosophical Transactions of the Royal Society B*, 376, 20190750.

Mahner, M., Bunge, M.
1997 *Foundations of biophilosophy,* Springer Science & Business Media.

Mancuso, S., Viola, A.
2015 *Verde brillante. Sensibilità e intelligenza del mondo vegetale*, Giunti, Firenze-Milano.

Mayr, E.
1974 Teleological and teleonomic, a new analysis, in Cohen R.S., Wartofsky M.W. (a cura di), *Methodological and historical essays in the natural and social sciences*, Springer, The Netherlands, pp. 91-117.

Mcshea, D.W.
2023 Evolutionary trends and goal directedness. *Synthese*, 201(5), 178.

Metzinger, T.
2017 *The Problem of Mental Action*, MND Group, Frankfurt am Main.

Michaels, C.F., Carello, C.
1981 *Direct Perception*, Prentice-Hall, Englewood Cliffs (NJ).

Morabito, C.
2020 *Il motore della mente: il movimento nella storia delle scienze cognitive*, Laterza, Roma-Bari.

Nansen, C.
2017 Unraveling the *«radiometric signals» from green leaves*, in M. Gagliano, J.C. Ryan, P. Vieira (a cura di), *The Language of Plants: Science, Philosophy, Literature*, pp. 62-68, University of Minnesota Press, Minneapolis.

Nick, P.
2021 Intelligence without neurons: a Turing Test for plants? *Protoplasma*, 258, 3, pp. 455-458.

Medin, D.L., García, S.G.
2017 Conceptualizing agency: Folkpsychological and folkcommunicative perspectives on plants. *Cognition*, 162, pp. 103-123.

Okasha, S.
2018 *Agents and goals in evolution*, Oxford University Press, Oxford.

Orians, C.M., Jones, C.G.
2001 Plants as resource mosaics: a functional model for predicting patterns of within-plant resource heterogeneity to consumers based on vascular architecture and local environmental variability. *Oikos*, 94(3), pp. 493-504.

Pacherie, E.
2011 Nonconceptual representations for action and the limits of intentional control. *Social Psychology*.

Parise A.G., Gagliano M., Souza G.M.
2020 Extended cognition in plants: is it possible? *Plant Signaling & Behavior*, 3, 1710661.

Penuelas J., Llusia J., Estiarte, M.
1995 Terpenoids: a plant language. *Trends in Ecology & Evolution*, 10, 7, 289.

Pievani, T.
2017 *La teoria dell'evoluzione. Attualità di una rivoluzione scientifica,* il Mulino, Bologna.

Raguso R.A., Kessler A.
2017 *Speaking in Chemical Tongues: Decoding the Language of Plant Volatiles*, in M. Gagliano, J.C. Ryan, P. Vieira, (a cura di), *The Language of Plants: Science, Philosophy, Literature,* University of Minnesota Press, Minneapolis.

Rigato, M.J.
2016 The agent as her self: how taking agency seriously leads to emergent dualism. *Rivista internazionale di Filosofia e Psicologia*, 7(1), pp. 48-60.

Searle, J.R.
1980 The intentionality of intention and action. *Cognitive science*, 4(1), pp. 47-70.

Segundo-Ortin, M.
2020 Agency from a radical embodied standpoint: an ecological-enactive proposal. *Frontiers in Psychology*, 11, 1319.

Segundo-ortin, M., Calvo, P.
2022 Consciousness and cognition in plants. *Wiley Interdisciplinary Reviews: Cognitive Science*, *13*(2), e1578.
2023 Plant sentience? Between romanticism and denial: Science. *Animal Sentience*, 8(33), 1.

Semchenko, M., Saar, S., Lepik, A.
2014 Plant root exudates mediate neighbour recognition and trigger complex behavioural changes. *New Phytologist*, 204(3), pp. 631-637.

Sharifi, R., Ryu, C.M.
2020 Social networking in crop plants: Wired and wireless cross-plant communications. *Plant, Cell & Environment*, 44(4), pp. 1095-1110.

Trewavas, A.
2003 Aspects of Plant Intelligence. *Annals of Botany*, 92, 1, pp. 1-20.
2004 Aspects of plant intelligence: an answer to Firn. *Annals of Botany*, 93, 4, pp. 353-357.
2014 *Plant Behaviour and Intelligence*, Oxford University Press, Oxford.

Varella, M.A.C.
2018 The biology and evolution of the three psychological tendencies to anthropomorphize biology and evolution. *Frontiers in Psychology*, 9, 400069.

Vodeneev, V., Akinchits, E., & Sukhov, V.
2015 Variation potential in higher plants: mechanisms of generation and propagation. *Plant Signaling & Behavior*, 10(9), e1057365.

Walsh, D.M.
2018 Objectcy and agency: towards a methodological vitalism, in Nicholson D.J., Dupré, J., (a cura di), *Everything flows: towards a processual philosophy of biology*, Oxford University Press, Oxford.

Wang, Q., Guerra, S., Ceccarini, F., Bonato, B., Castiello, U.
2021 Sowing the seeds of intentionality: motor intentions in plants. *Plant Signaling & Behavior*, 16(11), 1949818.

War, A.R., Paulraj, M.G., Ahmad, T., Buhroo, A.A., Hussain, B., Ignacimuthu, S., Sharma, H.C.
2012 Mechanisms of plant defense against insect herbivores. *Plant Signaling & Behavior*, 7(10), pp. 1306-1320.

Williams, R.J.
1956 *Biochemical individuality; the basis for the genetotrophic concept*. Wiley, Hoboken.

Witzany, G.
2008 The Biosemiotics of Plant Communication. *The American Journal of Semiotics*, 24, 1-3, pp. 39-56.

Witzany, G., Baluška, F. (a cura di)
2012 *Biocommunication of plants,* vol. 14. Springer Science & Business Media.