AN ALTERNATIVE APPROACH FOR DEFINING PLANT BREEDING

UMA ABORDAGEM ALTERNATIVA PARA DEFINIR MELHORAMENTO DE PLANTAS

UN ENFOQUE ALTERNATIVO PARA DEFINIR EL MEJORAMIENTO VEGETAL

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ABSTRACT

Currently, the definition of plant breeding most widely accepted by breeders describes breeding as the art and science of improving plant heredity to benefit mankind. According to the proponents of this definition, the art lies in the intuition, discernment or ability of the breeder to identify superior phenotypes, or in their capacity for making better decisions, etc.; while, the science of plant breeding, lies in applying the knowledge of various fields of science so that the breeder can achieve his goals. This study proposes an alternative approach for defining plant breeding. Considering that the various actions taken by breeders when carrying out their work depend on human cognition and emotion, it is suggested that breeding be defined as a science in which cognitive and emotional processes are employed to modify a plant genotype in order to make the plants more useful to man.

Keywords: Action. Cognition. Emotion. Concept.

RESUMO

Atualmente, a definição de melhoramento de plantas mais aceita pelos melhoristas descreve que o melhoramento é a arte e a ciência de melhorar a hereditariedade das plantas em benefício da humanidade. De acordo com os defensores desta definição, a arte dependeria da intuição ou discernimento ou da habilidade do melhorista para identificar fenótipos superiores ou ainda da capacidade do melhorista de tomar melhores decisões etc. A ciência do melhoramento de plantas, segundo a definição, implicaria na aplicação dos conhecimentos de várias ciências para que o melhorista possa alcançar seus objetivos. No presente trabalho, propõe- se uma abordagem alternativa para se definir melhoramento de plantas. Considerando-se que as várias ações dos melhoristas para realizar seu trabalho dependem da cognição e da emoção humanas, sugere-se que o melhoramento seja definido como a ciência em que processos cognitivos e emocionais são empregados para modificar o genótipo das plantas de modo a torná-las mais úteis ao homem.

Palavras-chave: Ação. Cognição. Emoção. Conceito.

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RESUMEN

Actualmente, la definición más aceptada de fitomejoramiento entre los fitomejoradores la describe como el arte y la ciencia de mejorar la herencia vegetal para beneficio de la humanidad. Según quienes defienden esta definición, este arte depende de la intuición o el discernimiento del fitomejorador, de su capacidad para identificar fenotipos superiores o de su capacidad para tomar mejores decisiones, entre otras. La ciencia del fitomejoramiento, según esta definición, implica la aplicación de conocimientos de diversas ciencias para que el fitomejorador pueda alcanzar sus objetivos. En este artículo, se propone un enfoque alternativo para definir el fitomejoramiento. Considerando que las diversas acciones de los fitomejoradores para llevar a cabo su trabajo dependen de la cognición y la emoción humanas, se sugiere definir el fitomejoramiento como la ciencia en la que se emplean procesos cognitivos y emocionales para modificar el genotipo de las plantas y hacerlas más útiles para los humanos.

Palabras clave: Acción. Cognición. Emoción. Concepto.

1 INTRODUCTION

Cognition — defined as the mental processes used by animals to gather, accumulate and use information about the external world — is fundamental to the decisions they make, such as where to live, what to eat or with whom to mate (Sol et al., 2025).

Various researchers have drawn attention to the importance of cognition in science. For example, Nersessian (2024) argues that scientific thinking is one of the most sophisticated expressions of the creative potential of human cognition. However, the way scientists think has, until now, played a limited role in research into cognitive science (Nersessian, 2024). Concern with the importance of cognition in research is not new: the book, ‘The Cognitive Basis of Science’, published more than 20 years ago, includes 18 topics on the subject (Carruthers et al., 2002).

Cognition is being studied in several areas, including aviation (Martins, 2016), education (Weidman and Baker, 2015), sports (Eldadi and Tenenbaum, 2025) and medicine (Stiegler and Tung, 2014). In plant breeding, the subject has been addressed rarely, directly or indirectly, in relation to decision-making. Directly, some articles have been published dealing with strategies (Kusmec et al., 2021), criteria (Jones and Cassells, 1995), models (Michel et al., 2025) and simulations (Sun et al., 2011) to assist in decision-making in breeding. Indirectly, the topic has been mentioned occasionally. For example, in defining plant breeding as both science and art, Hallauer et al. (2006) and Vencovsky et al. (2012) state that art remains a component of plant breeding since the breeder has to make decisions. In some articles, decision-making is considered one of the most important cognitive processes (Shahsavarani and Abadi, 2015).

The study of cognitive processes is crucial for understanding the way humans think (Shi, 2021), learn (Weizmann, 2023) and interact with the world (Olschewski et al., 2024). This allows for the development of interventions to address cognitive deficiency (Vance et al., 2016), improve educational practices (Cherukunnath and Singh, 2022) and enhance decision-making in various areas of life (Olschewski et al., 2024). Cognition differs among individuals (Logie, 2018), which can affect training in plant breeding and in improving the efficiency of breeding programmes. In medicine, probably the area where the most studies on cognition and emotion have been conducted, and excluding the fields that make up the cognitive sciences, such studies are relatively common. For example, it has been found that training in Surgical Cognitive Simulation has a statistically significant impact on improving surgical performance (Cragg et al., 2021).

Several of the suggested definitions for plant breeding are similar and consider it to have two components: art and science. For example, “Breeding is the art and science of improving plant heredity for the benefit of humankind" (Sleper and Poehlman, 2006). "Plant breeding is the science, art, and business of improving plants for human benefit" (Bernardo 2002).

The aim of this study is to present a definition for plant breeding from the point of view of cognition.

2 PLANT BREEDING AS ART AND SCIENCE

The definition of plant breeding as both art and science has now been accepted by several generations of breeders. The art of plant breeding implies the breeder's ability to discern, through observation, the differences between the plants they manage in order to make selections (Agrawal, 1998). As an art, plant breeding depends on the intuition and previous experiences of each breeder (Borém et al., 2002; Elsen et al., 2013), as well as requiring subjective judgment when planning and implementing a breeding program. The art of plant breeding also involves the so-called "breeder's eye"—the intuition that tells the breeder that one parent, progeny group or cultivar is better than another (Bernardo, 2002). The art of plant breeding lies in the breeder's ability to distinguish between desirable and undesirable plant characteristics, so that only plants with the best agricultural merit reproduce in succeeding generations (Chahal and Gosal, 2006). As such, the success of plant breeding depends on the breeder's ability to identify which phenotypes will be expressed in the next generation (Hallauer et al., 2006).

As a science, plant breeding depends on a theoretical and practical knowledge of several areas of science, including genetics, statistics, agronomy and phytopathology, among many others (Borém et al., 2002; Agrawal, 1998; Chahal and Gosal, 2006). The sciences related to plant breeding provide the breeder with an objective basis for deciding which parents to cross, which selection methods to use, which progenies to keep and which cultivars to release (Bernardo, 2002).

3 EVOLUTION OF THE CONCEPT OF PLANT BREEDING

The concept (Table 1) of plant breeding evolved (Duvick, 1996; Hallauer, 2011) based on when it was formulated, but it has never lost its essence of being the art and science of manipulating plants for the benefit of man (Hallauer, 2011).

Has the definition of plant breeding also evolved to keep pace with the evolution of the concept? Apparently, one could say yes, with two changes. Firstly, including science, since plant breeding was originally considered only as an art. Secondly, for some, placing more emphasis on science and, for others, more emphasis on art. Essentially, the definition has not evolved.

According to Hallauer et al. (2006), both art and science have contributed significantly to cultivar development; however the relative importance of art versus science has changed significantly over the last 150 years. Initially, phenotypic selection was practised between individual plants to obtain the ideal phenotype: success depending on the breeder's ability to identify phenotypes that would be expressed in the next generation. This ability to identify superior phenotypes depended on how effectively the plant breeder could visualise what might constitute superior improved cultivars. The art of the plant breeder was effective in developing cultivars that were phenotypically uniform for specific characteristics, however, the selected characteristics did not directly contribute to increased productivity. Selection was effective for characteristics of higher heritability, but relatively ineffective for those where heritability was lower, such as grain yield (Hallauer et al., 2006).

Figure 1

Concept and Definition

Concept and definition
Concepts are cognitive symbols (or abstract terms) that specify the characteristics, attributes or properties of a phenomenon in the real or phenomenological world that they are intended to represent and that distinguish them from other related phenomena (Podsakoff et al., 2016). The formation of concepts is the gathering and compilation of true statements concerning a given object. To determine the result of this compilation, an instrument is necessary. This instrument consists of any word or sign that can translate and establish the compilation (Dahlberg, 1978). From a scientific point of view, a concept is a cognitive symbol that has meaning for the scientific community that uses it (Podsakoff et al., 2016).
A definition is a statement that describes a concept, allowing it to be distinguished from other associated concepts (Lara, 2004). Definitions are indispensable assumptions in argumentation and communication, and are necessary elements in the construction of scientific systems (Dahlberg, 1978).

Science has become a more important component of plant breeding as fresh knowledge (from genetics, breeding, statistics and various other sciences) has generated methods, processes, techniques and concepts that help increase breeding efficiency. These concepts and studies, often referred to as ‘milestones in breeding’, have afforded a scientific basis for plant breeding. Several authors present lists of such milestones (Gonal et al., 2023; Ramalho et al., 2025).

Art, however, also remains a component of plant breeding, as the breeder needs to make decisions such as the choice of parents to be included in crosses, the size of the population to begin the selection, the phenotype preferred by producers (or clients), the generation(s) to be used for testing, and the target environments in which the cultivars will mainly be grown. But due to the statistical analyses available to assist plant breeders in their choices, such decisions are becoming ever more grounded in science (Hallauer et al., 2006).

It is the opinion of various breeders that plant breeding emerged as an art before becoming a combination of art and science (Elsen et al., 2013), and that the trend is for it to become more of a science than art (Hallauer et al., 2006; Jiang, 2013). However, for others, the trend is for it to remain more art than science (Duvick, 1996). According to Duvick (1996), plant breeders universally rely more on experience and art than on genetics.

4 AN ALTERNATIVE APPROACH TO DEFINING PLANT BREEDING

Definitions (Figure 1) that do not fully express scientific concepts can complicate learning a science and hinder the effective learning of a student. Poor definitions can be the result of (Wong et al., 2020) a lack of precision, lack of consistency, circularity and a lack of scope. (Podsakoff et al., 2016; Wong et al., 2020).

At least three points should be considered when defining plant breeding in terms of art and science. Art, presented as the intuition, distinction, skill, etc. of the breeder seems somewhat vague. There also seems to be some inconsistency among plant breeders: some value art more, others science. Thirdly, it can questioned whether art and science should be considered in isolation or whether they should interact? Should the definition of plant breeding include other components in addition to art and science? What are the underlying processes of art and science?

5 STAGES OF PLANT BREEDING

Plant breeding is a continuous and cyclical process that involves identifying plants with desirable characteristics (yield, quality, resistance to abiotic and biotic factors, etc.) and developing strategies to combine these characteristics in order to obtain superior varieties (Acquaah, 2012). Although plant breeding is a continuous process, some authors tend to divide it into stages or phases.

Schnell (1982) was the first to divide a plant breeding programme into stages. He considered the following: the generation of genetic variability, selection, and the experimental testing of cultivars. Other breeders began to consider the stages defined by Schnell (1982) in varying degrees of detail (Bishaw and Gastel, 2009; Ceccarelli, 2009; Weltzien and Christinck, 2009, among others).

6 ACTIONS

6.1 DEFINITION

Action control is one of the most fundamental topics in cognition, as humans interact with the environment through goal-directed behaviours, i.e. through actions. Action is a fairly generic term that describes several different types of phenomena, from a movement directed towards achieving a specific goal to behaviours in which the means and ends are temporally distant. The term action can be used in two ways: as a generic term indicating any type of intentional motor behaviour and as a specific term referring to goal-directed behaviours that produce a reward for the individual (Rizzolatti et al., 2001).

The notion of ‘action’ is not synonymous with ‘movement’; this concept will be used in the broader sense of ‘intentional action’. Such a notion implies that actions: (i) are motivated by goals and may or may not achieve those goals; (ii) often involve some degree of volitional control; (iii) require planning and decisions between alternatives; (iv) involve forecasting or anticipating an intended outcome; (v) are often, though not always, associated with a sense of agency, i.e. awareness by the agent of performing the specific action and of its objectives (Engel et al., 2013).

An activity comprises a pattern of multiple actions over time. Activities are intuitively far more complex than actions, but also better represent the actual life of a human being. This is because humans often carry out multiple actions simultaneously in a variety of temporal combinations (Liu et al., 2016).

Branchi (2022) defined behaviour as all the actions and associated mental states carried out or experienced by an individual in interacting with the environment. Behaviour includes everything an organism does, whether observed or not. This emphasis on behaviour should be valued in biopsychology, as behaviour is a crucial evolutionary determinant of survival. It is what organisms do (e.g. finding shelter, escaping predators, mating, or caring for offspring) that matters. As a result, the nervous system has evolved to meet the demands of interaction with and adaptation to the environment. As Engel and Schneiderman (1984) observed, “the raison d'être of the central nervous system is to optimise the organism’s ability to interact with its environment”. Behaviour is the way living beings interact with the world. Behaviour is a phenotype and, as such, depends on genetic and environmental factors. Behaviour is a product of a nervous system that processes sensory data from the environment: a nervous system that is integrated with the skeletal, circulatory, digestive and other systems to generate and regulate behaviours. The activities of this nervous system involve thousands of expressed genes but itself does not express behaviour. Although brain activity can be detected in the form of electrical impulses or bright spots on a computer screen during a brain scan, these phenotypes are not behaviours in themselves. Thought is an internal process that occurs in the brain but that cannot be directly detected by an external observer (Wahlsten, 2019).

6.2 TYPES OF ACTION

Humans interact with the environment in at least two different ways depending on whether the behaviour pattern is selected by the agents themselves or determined by external information (Wenke et al., 2009).

One type of action is carried out primarily in response to environmental demands. In this case, the choice of action is implied by external information. For example, it’s normal to stop at an intersection when the traffic light is showing red. Such an action is considered stimulus-controlled. Once stimulus-response associations are established, external stimuli trigger their associated reactions more or less automatically (Wenke et al., 2009).

In another type of action, the agents themselves select the appropriate action. This selection is usually aimed at producing a specific environmental effect or satisfying a particular need. This class of action has two distinctive psychological characteristics: it involves internal generation of the action and a mental representation of the effects of the action (Wenke et al., 2009).

The regions of the brain involved in these two types of action are separable, at least in part. The response to external stimuli predominantly recruits a circuit that involves the parietal lobes and lateral premotor areas. In contrast, the generation of internal actions depends more on the medial-frontal areas of the brain, including the supplementary premotor area and the cingulate motor areas (Wenke et al., 2009).

6.3FACTORS THAT INFLUENCE ACTIONS

Several factors influence an action, including: motivation (Aunger et al., 2025), sensation (Khilkevich et al., 2024) and perception (McDonough et al., 2019); biological and psychological factors such as genetics (Zhou et al., 2024), neurotransmitters (Sarmento Rivera and Gouveia, 2022), hormones (Asokan and Falkner, 2025) and physical health (Umegaki et al., 2021); basic bodily needs such as sleep (Pickersgill et al., 2022), learning (Coddington and Dudman, 2019) and memory (Heuer and Rolfs, 2020); personality traits (Akmal et al., 2025); social and cultural factors, which may include the presence of other people (Rolison et al., 2020), social norms (Zinchenko and Arsalidou, 2018), social expectations (Cloutier et al., 2011) and social context or background (Saltapidas and Ponsford, 2007); and the sensorimotor system (Riemann and Lephart, 2002). However, several authors discuss action in terms of two types of processes, cognitive and emotional, that take into account the above factors. The concepts of ‘cognition’ and ‘emotion’ are simply abstractions for two aspects of a brain at the service of action (Storbeck and Clore, 2007). Cognition and emotion contribute jointly to ongoing behaviours (Pessoa et al., 2012). The brain constructs not only concepts of emotion, but also cognitions and perceptions, all of which serve to guide action (Hoemann and Barretta, 2019). Cognitive processes have developed to enhance the preparation, execution and regulation of action (Kiesel et al., 2023); therefore, cognition serves action (Allport, 1987). Furthermore, it has been proposed that the distinction between cognition and emotion be eliminated (Pessoa, 2018; Pessoa, 2019).

7 COGNITIVE PROCESSES

Few authors have presented any definition of cognitive processes (Aizawa, 2015; Jarecki et al., 2020). Newen (2015), in a study entitled ‘What are cognitive processes? An example-based approach’, argues that cognitive processes can only be characterised with a clear scientific definition of what cognition is. According to Newen, cognitive processes are procedures that process all the information (be it multiple or complex) that human beings receive from the surrounding environment. This processing has the aim of transforming the information into easily manageable cognitive tasks (Newen, 2015). Table 1 presents a list of cognitive processes based on the brain model proposed by Wang and Wang (2006).

Is there any evidence that cognitive processes are involved in actions? According to Wurm and Eriguc (2024), recognising goal-directed actions is a computationally challenging task, requiring not only a visual analysis of body movements but also an analysis of how these movements causally impact and consequently induce a change in the target objects of the action. They tested the hypothesis that analysing body movements and the effects they induce depends on distinct neural representations in the superior parietal lobe and the anterior inferior parietal lobe. In four sessions of functional magnetic resonance imaging (fMRI), participants viewed videos of actions (e.g. breaking a stick, crushing a plastic bottle) together with stick figures in point-light displays, pantomimes and corresponding abstract animations of agent-object interaction. According to the authors, the results showed that the parietal cortex and the lateral occipitotemporal cortex are attuned to the physical characteristics of action, such as how body parts move in space relative to each other and how they interact with objects to induce a change (e.g. in position or shape/configuration). The high level of abstraction revealed by the results suggests a general neural code that underlies mechanical reasoning of how entities interact with each other and have an effect on one another.

8 EMOTIONS

8.1 THE NATURE OF EMOTIONS

Lindquist et al. (2022) argue that emotions are determined by both biological and cultural factors. According to those authors, academic debate about the nature of emotion traditionally pits biological and cultural influences against each other. One side of the debate emphasises the role of genetics, neurophysiological anatomy and the biological evolution of mammals as causal mechanisms of universal human emotions. These biological factors have led some scholars to look for emotional similarities among different human cultural groups, which are possibly the product of shared biological adaptations. For example, one study used machine learning to classify facial expressions that were repeated in 6 million YouTube videos across 144 countries during emotional events (such as weddings, sporting competitions and protests). The authors found global variation in the basic rate of emotional situations and in the movements of facial muscles that occurred in these situations, but they also discovered that an *a priori* set of 16 patterns of facial-muscle movements appeared worldwide. Each time a particular pattern occurred, up to 70% of the time and across various cultural contexts, it was in a similar situation (such as at a wedding). These findings have led researchers to conclude that discrete emotions are products of biological natural selection.

Table 1

Layered model of the brain (Wang and Wang, 2006, with modifications)

Subconscious processes		Conscious processes	
Layer 1 (sensations)	Layers 2 to 4 (memories, perception, actions)	Layer 5 (metacognitive processes)	Layer 6 (cognitive processes)
Sensory cognitive processes	Subconscious cognitive processes	Metacognitive processes	Higher cognitive processes
1.1. Vision	2. Memory	5.1. Attention 5.2. Concept Formation	6.1. Recognition 6.2. Images
1.2. Hearing	3. Perception 3.1. Self-awareness	5.3. Abstraction	6.3. Comprehension 6.4. Learning
1.3. Smell	3.2. Motivation 3.3. Disposition	5.4. Search 5.5. Categorisation	6.5. Reasoning 6.6. Deduction
1.4. Touch 1.4.1. Heat 1.4.2. Pressure 1.4.3. Weight 1.4.4. Pain 1.4.5. Texture	3.4. Goal definition 3.5. Emotions 3.6. Sense of spatiality 3.7. Sense of movement	5.6. Memorisation 5.7. Knowledge representation	6.7. Induction 6.8. Decision-making 6.9. Problem-solving 6.10. Explanation 6.11. Analysis
1.5. Taste 1.5.1. Salty 1.5.2. Sweet 1.5.3. Bitter 1.5.4. Sour 1.5.5. Pungency	4. Actions		6.12. Synthesis 6.13. Creation 6.14. Analogy 6.15. Planning 6.16. Quantification

The other side of the debate emphasises the roles of local ecology and cultural learning in the production of culturally relative emotions. Human groups live in different ecologies, follow different norms and values, and throughout history have experienced different levels of intergroup exposure. These cultural facts have led some scholars to assume that different cultural backgrounds vary how humans around the world experience, express and perceive emotions. For example, cross-cultural variation can be seen in self-reported emotional experiences in the neural correlates of emotional experience and perception, in producing facial-muscle movements and in perceiving emotion in the faces and voices of other people (Lindquist et al., 2022).

8.2 DEFINITION OF EMOTION

There is no consensus among researchers regarding the definition of emotion (Mobayed, 2024, for example). Kleinginna and Kleinginna (1981) reviewed the topic and proposed the following definition: emotion is a complex set of interactions between subjective and objective factors, mediated by neuro-hormonal systems that can (a) give rise to affective experiences, such as feelings of arousal, pleasure or displeasure; (b) generate cognitive processes, such as emotionally relevant perceptual effects, evaluations and labelling; (c) activate generalised physiological adjustments to conditions of arousal; (d) lead to behaviours that are often, but not always, expressive, goal-oriented and adaptive.

Izard (2010) administered questionnaires containing questions related to emotion to 35 researchers. She found that several researchers stated that emotion influences thinking, decision-making, actions, social relationships, well-being, and physical and mental health. However, there was no consensus among the researchers on a definition of the word emotion, and current data suggest that it cannot be defined as a unitary concept. Theorists and researchers have attributed very different meanings to emotion.

8.3 CLASSIFYING EMOTIONS

Ekman (1969) identified six basic emotions: anger, disgust, fear, joy, sadness and surprise. Anger is defined as fury, frustration and resentment towards others. Disgust is synonymous with aversion, distaste or repugnance, and is the most visceral of the six emotions. Fear arises in the presence of a stressful or dangerous stimulus perceived by the sensory organs. When the fight-or-flight response appears, the heart rate and respiratory rate increase. In addition, the muscles become more tense to deal with threats in the environment. Joy or happiness is a pleasant emotional state, synonymous with contentment, satisfaction and well-being. Sadness is the opposite of happiness, characterised by sorrow, disappointment and anguish. Surprise is triggered by an unexpected outcome to a situation, ranging from astonishment to shock.

Russell and Mehrabian (1977) proposed a dimensional approach in which any emotion is represented in relation to three dimensions: valence (positive/pleasurable or negative/unpleasant), activation (engaged or unengaged) and dominance (degree of control a person has over their affective states).

Plutchik (2003) proposed a model in the shape of a wheel comprising eight basic emotions that include joy, confidence, fear, surprise, sadness, disgust, anger and anticipation. The model describes emotions based on intensity, with strong emotions placed in the centre and weaker emotions placed towards the edge of a flower-shaped model.

8.4 EVIDENCE THAT EMOTIONS INFLUENCE ACTIONS

There are many studies that demonstrate how emotion impacts perception and behaviour. For example, Pereira et al. (2006) showed that viewing unpleasant images interfered with the performance of a basic non-emotional visual detection task. In a subsequent study, Pereira et al. (2010) used functional magnetic resonance imaging to test the hypothesis that, if the interaction of affective and motor signals underlies the effects of behavioural interference, the responses evoked by viewing unpleasant images would be correlated with the brain responses evoked during motor action. They further predicted that the slowdown in response times during unpleasant blocks might be linked to responses in regions of the brain involved in integrating emotional and motor signals, such as the cingulate cortex. As in the first study (Pereira et al., 2006), the participants performed a simple target-detection task following the presentation of unpleasant or neutral images. The results showed that an unpleasant emotional context modulated the responses evoked in various regions involved in the simple target-detection task (Pereira et al., 2010). In particular, the mid cingulate cortex was recruited when participants performed target-detection tests during the unpleasant context, with the signal responses in this region closely reflecting the behavioural interference pattern (as revealed by the reaction time). According to the authors, the results suggest that the mid cingulate cortex may be an important site for the interaction between negative valence signals and motor signals in the brain, and that it may be involved in implementing defensive responses.

9 RELATIONSHIP BETWEEN EMOTION AND COGNITION

Okon-Singer et al. (2015) showed that emotional signals, emotional states and emotional traits can strongly influence key elements of continuous information processing, including selective attention, working memory and cognitive control. This influence often persists beyond the duration of transient emotional challenges, perhaps reflecting slower changes in neurochemistry. In turn, the circuits involved in attention and working memory contribute to the voluntary regulation of emotion. The distinction between the ‘emotional’ and ‘cognitive’ brain is tenuous and context-dependent. In fact, there is compelling evidence that regions (e.g. dorsolateral prefrontal cortex, mid cingulate cortex) and processes (e.g. working memory, cognitive control) conventionally associated with cognition play a central role in emotion. Furthermore, supposedly emotional and cognitive regions dynamically influence each other through a complex network of recurring, often indirect, anatomical connections, in ways that jointly contribute to adaptive behaviour. Taken together, these observations show that emotion and cognition are deeply intertwined in the structure of the brain, suggesting that widely held beliefs about the main constituents of the ‘emotional brain’ and of the ‘cognitive brain’ are fundamentally flawed.

10 RELATIONSHIP BETWEEN THE ACTIONS OF PLANT BREEDERS AND COGNITIVE AND EMOTIONAL PROCESSES

With the aim of completing each stage of plant breeding, breeders carry out various activities, including writing texts, taking notes, acquiring materials and equipment; implementing, conducting and harvesting experiments; keeping or disposing of seeds, performing calculations, giving lectures, etc. An observer watching the plant breeder would see the actions used in these activities. For example, when the breeder is writing a text, the observer might note the arrangement of the breeder's fingers and hands on the keyboard, or when consulting a source, the breeder's gaze directed at the monitor, etc. In short, the observer would see the action processes, but not the cognitive or emotional processes. The former might include the choice of words, the way the text is organised, the topics covered, etc.; while the latter might include, among others, the joy of having done a good job, the fear of having failed to include relevant information, and the anxiety that some readers may not have understood what was written.

Marano et al. (2025) conducted a study that illustrates what has been presented regarding cognitive processes. They assessed how handwriting and typing differentially activate regions of the brain associated with motor control, sensory perception and higher-order cognitive functions. Handwriting activates a broader network of brain regions involved in motor, sensory and cognitive processing. Typing involves fewer neural circuits, resulting in more-passive cognitive engagement.

In terms of emotional processes, Citron (2012) found that more-recent electrophysiological studies, together with hemodynamic neuroimaging, have clearly demonstrated that emotional variables affect written word processing at the very early stages, facilitating and enhancing the processing of emotionally important words, and recruiting areas of the brain previously associated with both more-basic emotional processing (e.g. the amygdala) and emotional experience (e.g. the anterior cingulate cortex and the medial prefrontal cortex).

11 A DEFINITION OF PLANT BREEDING

Based on the above, the following definition of plant breeding is proposed: a science which employs cognitive and emotional processes to modify plant genotypes in order to make the plants more useful to man. This definition may have certain limitations. Existing knowledge of cognitive and emotional processes is still limited. For example, there is no consensus on how to define cognition and emotion. It is not known whether cognition and emotion are the same process. It is also still debated whether cognition is brain-bound or extended, embodied, embedded or enacted. However, the proposed definition will surely be improved as knowledge of the cognitive sciences increases.

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