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Potato Facing Global Challenges: How, How Much, How Well?

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Abstract This paper surveys issues and developments emerging from the keynotes and participants' presentations during the 20th EAPR Triennial Conference, held in Versailles, France, in July 2017, and puts them into the perspective of the general theme of the meeting: potato facing global challenges. It reveals important and far-reaching innovations in many areas of potato research, including breeding (genomic selection, high-throughput phenotyping, genome editing), plant protection (biocontrol) and seed production, but also a general innovation approach that follows an incremental pathway (and maintains many existing lock-in situations), and favours substitution strategies over system re-conceptualisation and testing, however urgently needed these might be to achieve or improve the sustainability of potato production in the medium to long run. While the assets and importance of potato as both a wholesome food and an essential part of future worldwide food systems were once more evidenced and highlighted, the contributions also revealed (i) a growing dichotomy between research activities carried out in high-income vs in low- or moderate-income countries, respectively; (ii) some gaps in the assessment of the sustainability of potato production in the medium to long run (external inputs such as fertilisers or pesticides, land and energy use efficiency); and (iii) persistent weaknesses in the integration of individual solutions into complete, operational potato production systems. Some areas for future investigations are identified.

Keywords Food security · IPM · Production systems · *Solanum tuberosum* · Sustainability

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Introduction

For a single individual to sum-up a conference like the EAPR 2017 may seem a vain exercise. This is because it can only provide a biased, personal view arising from partial exposure to the over 300 contributions, split into many parallel sessions, and, possibly even more importantly, from partial understanding of their contents. Indeed, these contributions cover a range of scientific disciplines, from the most specialised and analytic (physiology, genetics, plant pathology, etc.) to the most integrative and systemic (agronomy, systems analysis), each with their own technologies, research questions and applications; they are thus difficult to fully apprehend by 'outsiders' to these disciplines. Despite these limitations, the exercise may nevertheless be useful: for the conference organisers, by providing a hands-on assessment of the extent to which the conference objectives were met, but possibly also for the conference attendees, and to some in the scientific community who could not be present, by offering one or two synthetic or challenging ideas.

EAPR 2017 was a conference with a purpose: 'Potato facing global challenges'. Its chosen title contained the implicit promise that potato can help solve some urgent issues for mankind and for the planet. These issues can be grouped into three broad concerns: (1) food security and food safety for a growing population, requiring safer and healthier products for consumers and for the environment; (2) sustainable and environmentally friendly production, addressing the questions of resource management and use in integrated production system development, and making use of the newest technologies available (precision agriculture, big data, new breeding techniques, bio-control, etc.); and (3) innovation in practice, turning scientific inventions and discoveries into products and processes that will improve the performance of agricultural, or, better yet, of agri-food systems. The objective of this paper is to analyse whether, and to what extent, the scientific achievements presented during the conference allow to fulfil the title's implicit promise. A second but no least important pursuit is to identify the knowledge gaps still present, and the research options and the new directions that could be taken to bridge these.

To these ends, I had to make several choices. First, I will offer synthetic ideas rather than specific highlights, formulating them—whenever I can—as take-home messages. To put these into the perspective of the original aims of the conference, I will use the three challenges listed above as a thread to the presentation. Finally, I will try to offer a critical yet constructive perspective on the status of current potato research, assuming that the large number (more than 430 at the latest count) and diverse origins (some 50 nationalities present) of the delegates made the contributions to this conference an accurate sample of this field of agricultural research. I thus hope that the statements and ideas exposed here will echo over a larger audience than the one present in Versailles where the 20th EAPR Triennial Conference took place during this week of July 2017.

Some Key Achievements

Food Security The keynote papers delivered by de Ferrière le Vayer (2018), Dreyer (2018) and Schulte-Geldermann (2018), as well as several other contributions in the forms of oral communications or posters, support the idea that potato remains a great barrier to famine and, just as importantly, to malnutrition. The crop indeed yields high food production (in terms of energy per ha of land) even in hunger periods, over a large range of environments, and despite sometimes low yields (6 to 10 t ha^{-1} in some parts of South America and/or Africa, when the average under optimal conditions is close to 50 and can even reach or exceed 80 t ha^{-1}). This yield gap leaves lots of potential for further improvements and makes potato a prime candidate as a staple food in diversified diets. This is all the more true since potato has a high nutritional value. It provides energy, but also digestible proteins, much needed vitamins and microelements; the lack of which is a frequent cause of nutrition fragility in many parts of the world. As shown in the paper by Goyer (2018), this nutritional value can even be further enhanced by breeding for key vitamins, such as folate.

An essential asset of potato is that it is less affected by food price variation than cereals. This makes potato a crop adapted to both subsistence farming and income generation, which is crucial in its worldwide adoption as a pillar of sustainable agri-food systems.

Sustainable Production Often captured under the motto 'Producing more with less', this issue revolves primarily around the management of resources and optimising their efficiency, as analysed recently by Steyn et al. (2016) in South Africa.

The first of these resources is *fertiliser*, and more specifically nitrogen for which many optimisation efforts are still under way (on both timing and dose). Yet, applied doses still usually remain in excess of crop needs, sometimes quite considerably, highlighting that an economic translation of research results is still needed. These excess supplies of course generate unwanted side effects and force to design management systems of post-harvest N residues in soil, which however were alluded to as a perspective more than as current, ongoing research. By contrast with nitrogen, phosphorus and potassium were strangely almost absent from the talks delivered, which can only come as a surprise when realising that many agronomists consider phosphorus shortage as a major threat for agriculture in the next two to six decades (see Chowdhury et al. 2017 for a recent and comprehensive review). Micronutrients, such as iron and zinc, benefit from a renewed interest for 'biofortification', in the dual perspective of food quality (alleviating malnutrition or nutrition fragility; e.g. Diaz-Gomez et al. 2017; Schulte Gelderman 2018) and possibly of crop health (Kristufek et al. 2015).

The second resource under scrutiny is *water*. As reminded to conference participants by the lecture of George et al. (2018), potato is a thirsty crop, which needs a continuous supply of water to maintain its photosynthetic activity—which itself directly correlates to yield. The other side of the water coin is that it is also an essential component for the development of many fungal and bacterial pathogens, making the management of irrigation crucial for both crop physiology and crop health. Future climate predictions highlight increasing drought risks in Europe, except perhaps in Scandinavia. Just as important, these water stresses will often combine with more frequent heat stresses. Unfortunately, the interactions between these two abiotic sources of stress are still insufficiently analysed and understood, but their joint management will be crucial to maintain an adequate level of agronomic performance and tuber quality.

Pest control inputs also rank high among the resources that require a thorough management. The conference saw the rise of the search for biocontrol solutions, with a dedicated workshop, a complete scientific session and several presentations scattered into other parts of the programme. Most of these reported on ‘biocontrol candidates’, i.e. the screening for active substances or organisms able to reduce the growth, the reproduction or the epidemic development of major pests and pathogens. It is interesting to notice that efforts concentrate on currently ‘orphan targets’, such as the late blight and early blight pathogens which to date benefit from no such solutions. However, most of the screening and development work is only starting, so that, despite the many prospects under investigation and the sheer volume of development work underway, few field successes were confirmed. The most notable exception is potassium phosphite against late and early blight, whose dual mode of action (direct antimicrobial activity and stimulation of plant defences) makes uncertain candidates for registration on the ‘biocontrol’ list, and which are currently banned in organic agriculture in Europe (see EGTOP 2014 for a comprehensive analysis of potassium phosphite biological activity and status).

Several of the papers and posters delivered at the conference insisted on as yet often overlooked properties of these new means for crop protection. The first is that they are currently developed as substitutes to current pesticides, although they should best be seen as complements in integrated strategies. The second is that they are liable to cultivar-specific responses, meaning that their efficacy has to be assessed not in absolute terms, but relative to a host genetic context. This will of course make the prescription more difficult, but also calls for new phenotyping methods and traits for the host cultivars. Third, and equally important, is the fact that specific management tools (in the form of decision support systems and/or modules fitted to plant defence stimulation or to biocontrol products at large) are still blatantly missing. This is a pity, for one cause of the limited efficacy in the field of preparations very active in the lab might come from inadequate positioning and application schedules.

This last remark leads to the current explosion in the development of so-called IPM toolboxes. Such compilations of technologies and advice have been displayed for most pathogen and pest groups, including insects, blights, powdery scab and bacterial rots. Most of them still put a strong emphasis on pesticides whenever these are available and then tinker with application rates or frequency. They also rely increasingly, and this is more of a novelty, on epidemiovigilance and population monitoring on the one hand and on warning systems and risk assessment software on the other.

The fourth area in the potato production chain where input management is a key issue is *storage*. Potato storage is still very much dependent on CIPC, but residues of this chemical in the food chain become an ever-increasing issue. Measuring, lowering and eventually banning these residues are the topics for a large corpus of investigations. The quest for substitution products, such as essential oils, is still ongoing, but does not entirely solve the problem, as these oils can also leave residues themselves and may alter the quality for use of the stored tubers. Improved application methods, allowing to lower the doses applied while keeping a high presentation quality of the stored crop, are also an active area for technological research.

Potato and Innovation Two main ideas regarding innovation patterns for or with potato emerge from the conference. The first is about scale, towards bigger and more complex datasets and technologies; the second is about actors, with increasing occurrence of multi-actor and participatory dimensions.

Thinking Big… and High Tech The high-throughput, big data era is here. Long restricted to the molecular -omics, it now extends to phenotyping, with sets of new technologies based on sensors and image analysis available and more and more widely used now (Kempenaar et al. 2018; Slater et al. 2018). These open the way to new concepts and disciplines, such as 'survivalomics' and genomic selection in breeding. They offer the possibility to diversify the breeding targets, both in terms of traits (for instance increasing the folate contents of tubers for improved nutritional quality; Goyer 2018) and of production environments, with the selection of specific ideotypes for local environments, in a 'tailored breeding approach' (Slater et al. 2018). The definition of breeding values and of the genomic selection equations, allowing to predict the phenotypic values for combined traits from alleles detected at a large number of loci, remains a challenge in a tetraploid organism like the potato, but this work is already underway. I was however stricken by the fact that, although the potential for 'big data' approaches in our favourite crop is evident, given its wide distribution and diversity of uses, actual practical achievements are still scarce in potato.

The high-tech dimension, alluded to in the previous paragraph with the development of sensors, multispectral cameras, drones and cosmic ray neutron probes for the characterisation of plant phenotypes and of their physical environment, also pervades breeding techniques, with the very fast expansion of new breeding techniques based on genome editing, especially with the CRISPR-Cas9 system (Rogowsky 2018). These gene editing technologies allow to 'tailor' alleles for disease resistance, product quality or agronomic traits, and to design new combinations without the problems of linkage drag common in conventional breeding schemes through sexual crosses. While their applications in potato are at the moment only at an experimental stage, it is a safe bet to take that cultivars derived from these gene editing technologies will be released to the market within the coming years, although their legal status is still pending.

The massive data flow generated by the increase in typing throughput and by automated environmental sensors imposes developments in prediction models, allowing to change scales between the data collection and the prediction. This change in scale can be a matter of size (for example, going from allele and gene sequences to predicted plant phenotypes, as proposed by the genomic prediction equations used in genomic selection), but also a matter of numbers (e.g. predicting one phenotype from hundreds or thousands of marker sequences). Therefore, the efforts in computational biology and data exploitation are at the forefront of the current digital revolution. They also concern the automated data extraction in image analysis software used for phenotyping, or the development of software pipelines to connect genetic information to predicted metabolic networks (Rogowsky 2018).

All Along the Innovation Path There is more to innovation than discovery, as innovation is often defined as 'an invention that met a market'. This is why innovation requires a (sometimes) long chain of actors, from research to consumers through legislators and industry (see for instance Andrivon 2012). This interplay and multi-actor dimension is now well apparent in the many participatory initiatives to bring research and end users closer to each other, as highlighted in potato R&D projects in developing countries (Dreyer 2018; Schulte-Geldermann 2018), but also in public-private partnerships in developed countries. The participatory approach allows a better identification of invention targets (Kolech et al. 2015), the form and nature of stakeholder involvement (Reichert et al. 2013) and hence a better efficacy of research and increased adoption by end users. It is however important to notice that there is not a unique way to develop and use participatory actions to foster innovation in potato production systems and that the local context often dictates which scheme can or should best be used (Ortiz et al. 2013).

The two most crucial issues for innovation are the availability of new inventions on the one hand, and the acceptability of new solutions on the other. When applied to potato production, we have seen in the above paragraphs that the invention flow is steady in all areas of research. However, it is quite striking that some innovation prototypes, the development of which might be expected given the current concerns for a more environmentally conscious, locally adapted agriculture, were mostly missing from both the conference presentations and the general potato literature. Among such prototypes rank 'cultivars with users' manuals' (that is, deployment recommendations according to the type of pest resistance — e.g. Andrivon (2009)—or general agronomic performance bred in those genotypes), and innovations based on the exploitation of genotype × environment interactions for stress management.

It should be noted that the development costs of inventions to suit market requests can be high, and the infrastructure and business ecosystems often slow down transfer to end users. The psychological and cultural dimensions also play a very strong role in industrial decision-making regarding innovation (see for instance Chataway et al. (2004) or Hall et al. (2011) for examples in other agriculture sectors) and often overlook the conditions for acceptability by end users, which is a key issue in both developed and developing agricultures (Baret 2018).

Assets… and Concerns

Old Issues … … New Solutions or Options

From the above description emerges a familiar picture. The major challenges facing potato and its assets to address them remain indeed very similar to those that a wider historical perspective, such as the one offered by de Ferrière le Vayer during the conference or by Salaman and Hawkes decades ago, also highlighted. The potato value to feed the world sustainably remains undisputed, as is the recognition that quality seed is a sine qua non step for success. The value of the potato gene pool for breeding, and even for exploiting new traits, is also widely recognised, and the existence of gene banks with well-characterised accessions is an essential asset to give access, but also to ensure the exploitation of these valuable gene pools. The vulnerability of the crop to a large number of pests and diseases, which current global changes only enhances, remains one of the most severe threats to a wider adoption of the potato and its sustainable cropping. While the pessimist will conclude that the scientific community working on potato is actually making little progress and still has to address the same issues for want of suitable and long-lasting solutions, the optimist will think that we can learn from the past and do not need to re-invent all from scratch every time: de Ferrière le Vayer (2018) quite convincingly showed that the issues potato is facing in Africa today are very similar to those it met in Europe during the first half of the twentieth century. With the benefit of hindsight, it is now up to us not to make the same mistakes twice, and not to re-create the lock-in situation of extreme dependency to inputs that we now have in developed countries and which make a change in production systems so challenging (see Baret 2018).

However, the current and upcoming contextual changes, particularly in climate, impose to revisit some of these familiar issues in a totally renewed perspective. For instance, the increase in CO_2 contents in the air might boost yields (CO_2 fertilisation; Haverkort et al. 2013), but also foster longer growing seasons and/or earlier planting (a trend already well underway in many European countries). Will this lead to new production areas, as Denis Gaucher suggested with potato as a winter planted crop in southwestern France by 2100? Will this decrease the risk of some diseases, such as late blight (e.g. Launay et al. 2014), but favour the emergence of new pests, particularly insects and the microbes and viruses they can transmit? Many simulation exercises, based on IPCC scenarios and biology models, are underway and suggest that future potato cropping systems could well differ markedly from those we know today. The cultivars will have to adapt to these new environments and cropping situations, and this imposes that we start thinking now of the traits that will have to be combined in these future cultivars.

Breeding differently is therefore one of the next big challenges ahead. While potato breeding has long targeted all-purpose cultivars, performing well across a large range of environments and hence able to gain large market shares and maintain them for decades or more, the focus is now on selecting cultivars with narrower niches, be that in terms of uses or of production environments. This change implies to shorten the breeding time, paving the way for a more widespread use of the high-throughput phenotyping and genotyping technologies required for association genetics and genomic selection (Slater et al. 2018) and possibly also for gene and genome editing (Rogowsky 2018). It also requires to diversify breeding targets, in terms of traits (micronutrient and vitamin contents—Schulte Gelderman 2018; Goyer 2018) but also of stress resistance, taking a particular attention to stress combination and side effects. For instance, George (this volume) highlights the fact that climate change will induce both drought and temperature increases, and hence the need to develop cultivars with joint tolerance to both of these abiotic stresses to maintain photosynthesis and hence yield. As discussed above, the recent development of participatory breeding helps to best define the crucial trait combination targets, and to facilitate acceptance of new genotypes by growers (Kolech et al. 2015; Dreyer 2018; Schulte-Geldermann 2018).

Of course, such breeding work can only be implemented if the suitable gene pools are available. The large worldwide potato collections host a remarkable diversity of *S. tuberosum* and related species, whose maintenance is however cumbersome, as shown by several talks during the conference. The definition of core collections, encapsulating most of the genetic diversity within a reduced number of clones, has thus been attempted and achieved for several tuber-bearing *Solanum* species (Hardigan et al. 2015; Bamberg et al. 2016; Esnault et al. 2016). However, the revolution in potato breeding goes further than the redefinition of target traits and combinations, as there was a recent proposal to entirely change the breeding system of the tetraploid, vegetatively propagated crop into a diploid, inbred crop propagated via true seed (TPS; Jansky et al. 2016), and impacts directly which seed production and certification systems can be implemented (Quéré 2018). Some European companies are now exploring this route, but the heated discussions about TPS during the conference clearly show that there is no current consensus as to the value of this new approach.

The other striking area where a new perspective shows up is biocontrol. Up to now, most communications on potato health at previous EAPR conferences dealt with systems based on chemical control, and when this was not applicable (bacteria, viruses) on prophylaxis and seed certification. Fortunately, there is now a flow of new research targeting biocontrol at large, be it through plant defence stimulators, biocontrol micro-organisms, or even alternative pesticides (phosphites). Most of the papers and posters in this area at the conference were reports of screening possibly active solutions and were still far from actual field applications. However, progress in this direction is notable, especially with 'natural biocides' that may have also a plant defence stimulation activity (see talk by Liljeroth et al. during the conference). Much is still to be done to fully use and integrate these new control means into viable systems, but the impetus is there now.

Towards Future Research…

… Objects Biodiversity will remain a crucial investigation object for potato research at large for the foreseeable future, in both its favourable (gene pools for breeding—see above; biocontrol agents; microbial communities associated with crops—Pfeiffer et al. (2017)—and affecting plant phenotypes, for example by promoting growth—Xia et al. (2015)) and nasty (pests and emerging threats) components. It was surprising that only few papers, in particular those of M. de Vries and of L. Greenville-Briggs, dealt with the analysis of beneficial microbial communities and their impact on plant phenotype expression. Does it mean that the 'phytobiome' era has not fully hit potato yet? Maybe… Let us not forget either the soil microbiomes, not directly linked to the plant rhizosphere, but active in the nutrient cycling and direct or indirect control of soil pathogens (Ghorbani et al. 2009).

Models are the other type of objects which should probably see many developments in the future. While models are being used for a long time now in various areas of potato research, from plant growth to risk assessment, the 'Digital Potato' era, with its steady flow of massive and varied data (numerical measurements, digital images, genome and gene sequences…), will foster a new set of models to be developed, for a more accurate prediction of genotypes (especially in tetraploid *S. tuberosum*) and phenotypes, and hence prediction equations readily usable for genomic selection. Since the data flow concerns not only the plant and its cohort of associated organisms, but also their abiotic environment (local climate, soil, etc.), one can hope that the joint use of all the big data available now, and more and more automatically and easily collected through miniature sensors and wireless transmission will result in improved Decision Support Systems.

… Topics There are two main options to increase food security, which is still of paramount importance for the future of potato research: (1) to produce more with less, through better input management and optimisation and relying on resource use efficiency approaches, as discussed above; and (2) to produce just as much, but waste (much) less, both before and after harvest, through better tuber handling, improved storage facilities, more efficient processing and marketing operations, and increased involvement and awareness of consumers. This second option has not been extensively tackled during the conference, whereas the first has received consistent attention. It is also important that both options are of course not mutually exclusive, but should best be combined to increase the overall sustainability and value of the potato industry.

… and Aims Sustainable potato cropping is an obvious goal for the future. This leads to the lurking million dollar question: is potato low-input, or can it/should it be? Addressing this question has at least two dimensions: resource consumption and management, and practices.

The resource issue has been briefly alluded to above, with the examples of pesticides, fertilisers and chemical inputs for storage, as well as water. There were however two other kinds of resources that were barely mentioned during the conference: energy and land. Designing a low-carbon print potato industry, in the primary production stages but also during storage, processing and distribution, is a very big challenge. The few investigations on system comparison, with greenhouse gases emission assessed through modelling and not taking the processing and marketing stages into account, show the extreme variability of carbon prints across systems, with prevalent effects of irrigation, fertilisers and storage, but also a clear trade-off between carbon and land footprints (Haverkort et al. 2014). Therefore, the objective of sustainability will necessitate hard-to-find compromises, and these compromises will probably vary between the different impacts production areas.

From Tactics to System Management and Engineering? As shown above, many of the innovations in the different areas of potato research are currently incremental innovations, that is step-by-step improvements of an otherwise unaltered structure. While this approach has the value of not de-stabilising an established industry, it perpetuates lock-in situations and prevents the attainment of more ambitious objectives, such as the suppression or drastic reduction of pesticide use for instance (see Baret 2018). IPM is a prime example: while its current status, as illustrated in the description and examples provided by Verjux (2018) and Baret (2018) is that of incremental adjustments to a long-established system based on regular, and sometimes massive, use of pesticides, it is also an area in which extensive system redesign, to accommodate and combine solutions with partial effects but also address the non-pathogenic stages of pathogens and pest (i.e. the primary inoculum sources) through crop husbandry, prophylaxis and intensive scouting, is needed if the objective of halving pesticide use within a few years is to be reached (see for instance Penvern et al. (2016) for an example in orchards, and Baret - this volume and Andrivon (2012) for a discussion of motivations, means and consequences).

One of the next frontiers to conquer in the realm of biodiversity for potato research is to switch from managing diseases one at a time to managing the crop health at large, i.e. disease complexes attacking the crop simultaneously or sequentially, including all new emergences (zebra chip, several insect pests, etc.) that are as many moving targets. This is a very large gap to cross, as it requires a detailed knowledge of ecological interactions between pathogens on a single host plant, a capability of predicting the timing of infections for various pests, both aerial and on the underground system, and functional models to predict the outcomes of management practices directed against one of the complex members on the development of all others (including the feedback loops that such management actions can generate). There have been remarkably few papers published so far on these topics, and this is an almost entirely virgin land to explore for research: however, it is obviously crucial if sustainable, IPM strategies are to be developed.

The set of issues above makes it increasingly clear that sustainable potato production and use will require, in the not too distant future, more or less extensive adjustments and redesigns of the cropping and processing systems. If sustainability is to serve as the Ariane thread to think these changes and get into Integrated Production Management, taking into account the range of trade-offs between impacts that are to be accommodated, do we have all needed solutions handy? A conference such as EAPR 2017 reveals abundant knowledge and prototypes that could serve as many bricks for the design of new production systems. There is a steady flow of discovery and invention within the potato research community, and it generates many individual solutions. In my view, the weak links towards a true systems approach are actually two: first, a lack of involvement in our specific needs of persons trained in systems theory and management; second, a lack of long-standing, large-scale experimental sites where the new systems could be tested (and compared with current ones) under actual operation conditions and in designs allowing a multicriteria analysis of their outputs relative to the various dimensions of sustainability. There is no single immediate answer to these shortcomings, but academic research, extension, engineering and recurrent funding are needed if they are to be overcome.

EAPR2017 was very much a global conference, with over 50 countries from all over the world sending delegates and contributors. More than any previous one I attended in the series, it left me with the lasting impression of a growing dichotomy of research activities for and between developed and developing countries. This was true in terms of targets and research goals, but also of methods (with for instance a clear trend in developing countries for participatory research activities, which are much less present in high-income countries) and operation (mostly lab and desk in developed countries, mainly field and extension in lower-income countries), although some of the long-term concerns were actually the same (robust seed systems, sustainable and quality food production with less inputs, etc.). I am afraid that if we let the gap enlarge, the result will be two communities sharing only one object, but losing a common perspective. The current menaces over funding programmes for agricultural development by developed countries, and the trend, just as strong, of shrinking numbers of students in agricultural sciences in the same countries, ring loud bells in this respect. Let me thus hope that these menaces will remain temporary and that the next EAPR conference, in Warsaw in 2020, will bring exciting developments and renewed perspectives to give *Solanum tuberosum* an even firmer role in worldwide food security.

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