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Review article

Impact of research on maize production challenges in Hungary

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ABSTRACT

Maize (*Zea mays* L), as a major cereal crop produced in Hungary in addition to wheat, attracts enormous research from both educational and non-educational institutions. Research is aimed at addressing the key abiotic, biotic and social economic constraints. The stakeholders and institutions involved in research are spread all over Hungary. Currently, no review has been done to comprehensively reveal the trend of maize research in Hungary, as well as key players such as institutions, universities, industry and researchers. Hence, this bibliographic review was conducted to: i) identify the major research institutions and their contribution towards maize research in Hungary; ii) evaluate the major maize research areas in Hungary between 1975 and 2022. Literature search was conducted in Web of Science (WoS) database using keywords; 'maize' OR 'maize' + 'Research' + 'Hungary'. Bibliometric analyses were performed using the VOSviewer software. Changes in the publication trend of documents was tested using Mann Kendall Test. A total of 947 publications related to the topic were published by 441 institutions between 1975 and 2022. There was a significant ($p = 0.001$) positive increase in the number of published documents. Hungarian Academy of Science (210 documents) and University of Debrecen (132 documents) recorded the highest number of publications contributing 58.7% of the maize research literature in Hungary. The major research areas included: increasing maize yield, hybrid development, pests and diseases, irrigation, fertilization (nitrogen), drought, temperature, gene expression and climate change. The increasing number of published documents signifies an improved response to addressing maize production challenges through research in order to boost its productivity.

1. Introduction

Cereal crops and associated products provide the major fraction of human nutrition on a global scale [1]. FAO [2] report shows that world cereal production in 2022 increased by 8.3 million tonnes (0.3%). Maize (1151.36), wheat (783.8), rice (502.98) and barley (150.48) are the major cereals grains produced globally [2]. Maize (*Zea mays* L.) was adopted as a domestic crop more than 9000 years

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ago in southern Mexico [3,4]. Currently, its global production has exceeded a billion metric tons annually [5]. Maize has high adaptability potential to different agro-ecological and climatic regions, therefore, large quantities are produced as food for humans, feed for livestock, and raw material for agricultural processing industries [6]. According to FAO [7], the world's population is estimated at 9.7 billion people by year 2050, and the biggest question humanity seeks to answer is how to feed this constantly growing population. Maximizing maize production and productivity partly answers this question by stabilizing agro-food systems and promoting food security [8–11]. Stabilizing maize production involves the holistic management of production inputs, soil fertility, integrated nutrient management and adoption of climate smart adaptation strategies [24], among others.

Maize is one of the major cereal crops produced in Hungary [12] for both consumption and export. Maize occupies the largest sown area of 1 million hectares, followed by wheat and barley [13] with an annual production of 6–8 million tonnes. The utilization of maize output is distributed as 48% for exportation; 33% as livestock feed, 18% for agro-processing industry, and 1% used for seed production [13]. At the industrial level, ethanol and soluble distiller's grains are the co-products [14]. Owing to these benefits, maintaining optimum maize production becomes a key factor. Although the average maize yield has been changing every year, it remains superior to the rest of the cereals in that period (Fig. 1), [15]. Generally, sustaining the superior yield of maize and other crops requires fertile arable land and plant fertilization [142,144], nutrition and nitrogen application [140,143,144], irrigation and water supply [140,144, 145], favourable weather and climatic conditions [16,146], judicious use of agrotechnical inputs and continuous research to develop new innovations.

1.1. *History of maize research in Hungary*

Historically, maize research in Hungary started with the breeding of maize hybrids. The development of maize hybrids started much earlier using variety crossing, performed by different researchers. In 1933, 12 variety hybrids were crossed by Rudolf Fleischmann and 171 varieties in 1948 by László Berzsenyi-Janosits [17,22]. Of all these varieties, only four hybrids, namely *Óvári* 1, *Óvári* 3, *Óvári* 4, *Óvári* 5 were granted state registration in 1953, and this was a major breakthrough and marked the beginning of successful hybrid research in Hungary. Endre Pap was born in Mindszentpuszta, Hungary achieved the intellectual rights for the Martonvásári 5 (Mv 5) maize hybrid development on 16th December 1953 after crossing inbred lines [18]. This was a milestone in maize production not only for Hungary but the first maize hybrid developed and registered in Europe [17,18]. The Martonvásári 5 hybrid characterised by higher yield potential, higher adaptability and mid-early ripening made it a favourable maize hybrid that was successfully grown in all parts of the country but also in other European countries [18]. This led to the establishment of hybrid maize seed plants across Hungary; Mezőhegyes, Baja, Mezőnagymihály, Boly, Debrecen, Murony established in 1958, and Dalmand, Mezőfalva, Szenttamás, Mosonmagyaróvár, Cegléd and Hódmezővásárhely between 1959 and 1964 [17–19], laying a strong foundation for Hungarian hybrid maize seed industry. Such a strong foundation has yielded important results boosting maize production, productivity, research and maize exports in Hungary.

The registration of the Mv 5 maize hybrid in 1953 kicked off hybrid maize breeding in Hungary and Europe in general. Hybrid maize growing occupied all (100%) maize growing areas of Hungary since 1964 [19]. Different studies demonstrated the performance of hybrids in Hungary; Frey [20], noted that first maize hybrids had a 7–11% yield more than other varieties, with 49% surplus yield for Hybrids developed in the 1960s [21]. Maize hybrids developed in the 1980s had a 66.4% (4.21 t/ha) higher yield than open pollinated varieties, and when compared to those developed in 1930s, they had a 27.5% (2.28 t/ha) higher yield [17]. Plant stocking density increased hybrid superiority when compared to open pollinated varieties [22]. Variety hybrids were not as popular as inbred hybrids because of their high yield (10–15%) [21] and this gave direction and set research trend to develop more highly productive hybrids in order to boost maize production in Hungary.

The agro-ecologic potential of Hungary and its utilization has greatly decreased [23], thus necessitating the need for robust research to bridge the gaps caused by drought, soil infertility, pests and diseases, climate change [10]. Maize production, similarly to other cereals requires major resources such as light, water [140,144,147], air [24], soil fertilization and proper agronomic management practices [16], for proper development. However, optimizing the utilization of these resources requires efficient and effective technologies which are generated through robust research. Research interventions underpinning interactions between soil characteristics, climate, and crop agronomic management practice ensure improved crop productivity, production and sustainability [25,26,

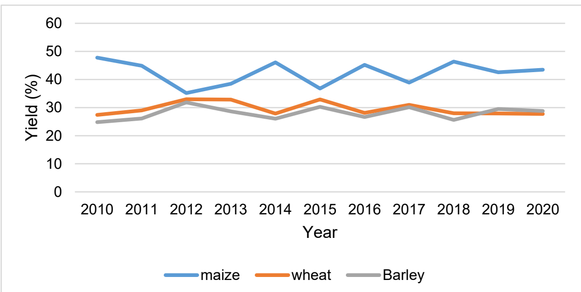

Fig. 1. Percent yield of three major cereal crops in Hungary, 2010–2020.
Source: Hungarian Central Statistical Office data, 2021.

147] have been carried out in large numbers by different institutions in Hungary. However, no current review has been conducted to comprehensively reveal the level of linkages, key areas of research and stakeholders involved in maize research in Hungary. However, this information is vital for decision-making on resources allocation, re-categorisation, reprioritisation. In this context, carrying out research review that maps and evaluates the existing and already published literature and identifies possible research gaps [27,28]. Consequently, this review was conducted in order to: a) identify the major research institutions and scientists, their contribution towards maize research in Hungary; b) evaluate major maize research areas in Hungary between 1975 and 2022. Overall, this would answer the critical question; how does research impact on maize production challenges in Hungary?

2. Materials and methods

2.1. Database identification, literature search and screening

The field of science contains a wide range of scientific literature archived in various databases, namely Google Scholar, PubMed, Scopus, Web of Science (WoS). In this review, the authors chose Web of Science, since it is one of the oldest, authoritative and widely used database containing research publications and citations across the world, covering approximately 34,000 journals [29]. In fact, WoS as a data source and a major literature archive contains peer reviewed articles, has simple and user friendly interface thus making bibliographic review of literature and data visualisation easier using softwares like VOSviewer [30].

This review analysis was conducted in different stages (Fig. 2). Firstly, the authors generally searched all the scientific literature available regarding maize research in Hungary in the WoS database. The search was conducted using keywords; 'maize' OR 'maize' + 'Research' + 'Hungary' (MRH). The search was restricted by topic (title, abstract and keywords) which retrieved a total of 135,715 documents. The number of documents was unmanageable, therefore, search was restricted by only title which yielded 58,548 documents. Further restriction was conducted by country (Hungary) yielding a total of 1027 documents (https://www.webofscience.com/wos/woscc/summary/4f9feb38-ed3e-45c3-adbf-c955db8deeed-93ed6959/relevance/1). Manual screening and the evaluation of documents was conducted following the exclusion and inclusion criteria. Inclusion of documents was based on contribution towards maize research development areas such as maize yields (quality and quantity, abiotic and biotic stresses), while documents on maize topics such as maize exportation and/or importation, were excluded yielding 947 documents. The final 947 records retrieved containing Hungary literature were distributed as; 687 research articles, 209 review articles, 35 book chapters and 16 books, all published 1975–2022.

2.2. Data exportation and analysis

Metadata of the 947 documents was exported as a csv file from WoS. Meanwhile, the number of published documents were converted into Microsoft Excel format and publication trend was analysed with the Mann Kendall Test using EVIEWS software. Bibliometric analyses were performed using the VOSviewer bibliometric tool [138]. The key units of analysis in bibliometric synthesis included: co-authorship (authors and institutions), co-occurrence (author keywords and all author keywords) and citations (by authors, documents, and organisations).

3. Results and discussion

3.1. Overview of MRH trend

The 947 publications included in this bibliographic review were published between 1975 and 2022. Publication trend results using Mann-Kendall analysis showed a significant positive increase ($p = 0.0001$) with the model fit value 53% (Fig. 3). The number of publications have been clustered; first cluster between 1975 and 1988 with fewer publications, 1975 recorded 0.4% of published documents with negligible increase until 1989 where progress was significant at 2.42%. However, there was slight decrease in documents published in 1989 and 1990 from 2.42% to 0.74%. The trend of publication was a slightly increasing curve up to 1998, attaining 3.28%, representing a 2.88% growth in publications on MRH between 1975 and 1998. The publication year 1999 recorded a decrease in documents published (1.97%), compared to the previous year (3.28%). Subsequently, a significant increase in publications was attained up to the year 2008 with the highest percentage publication (5.49%) of all studied years. After the highest peak year 2008, there was a decrease (3.36%) in publication the subsequent year 2009 (2.13%). Later, a normal publication trend with slight increase per year was obtained up to the study year 2022 (3.53%). The percentage increase for the last cluster between 2010 (2.13%) to 2022 (3.53%) was 1.4% an indication of slight increased to addressing maize research in Hungary. Fig. 4 indicates the general

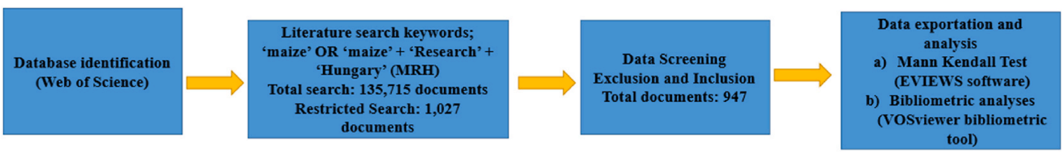

Fig. 2. Summary of the data search cretaria

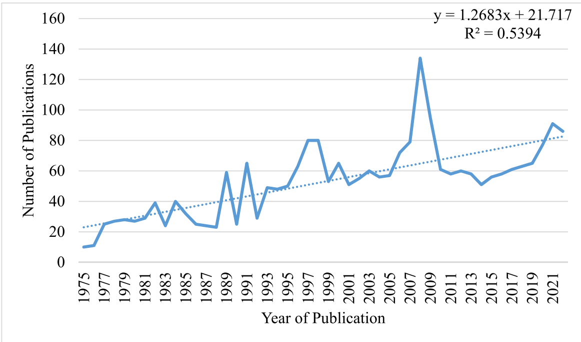

Fig. 3. Publication progress on MRH between 1975 and 2022: MRH; Maize, Research, Hungary.

distribution of published documents by WoS categories (subject area). The distribution of the subject area was: Agronomy (64.26%), plant sciences (23.56%), environmental sciences (4.1%), biochemistry and molecular biology (3.99%) and soil sciences (3.7%). The increase in published documents as well as wide distribution of research areas directly relates to an increased response to addressing maize crop challenges through research in order to boost its productivity. Publications play key role towards sharing important knowledge amongst organisations, institutions, people and industry [31,32]; optimise effectiveness, efficiency, and competitiveness of the academic output of institutions and universities [33]. Promotion of publications and sharing of knowledge amongst academicians, leaders, populace requires good social relationships and interactions [34].

3.2. Institutions involved in MRH between 1975 and 2022. MRH: Maize, Research and Hungary

A total of 441 organisations/institutions published documents on the MRH topics. The highest number of documents was published by the HUNGARIAN ACADEMY OF SCIENCE (210 documents) and the UNIVERSITY OF DEBRECEN (132 documents), contributing 58.7% of the MRH literature. These were followed by SZENT ISTVAN UNIVERSITY, EOTVOS LORAND UNIVERSITY and UNIVERSITY OF PANNONIA that published 60, 32 and 26 documents, respectively. All of the above institutions are categorised as universities, which indicates that maize research and development in Hungary is spearheaded by universities which are in direct contact with industries for research spin off and commercialisation of technologies. The non-academic institutions (mainly companies) that published documents on MRH included: CEREAL RESEARCH NON-PROFIT Ltd, CABI EUROPE SWITZERLAND, BARN BIOLOGY RESEARCH CENTER, INRA and OAKLANDS published 9, 8, 4, 3, and 2 documents. Institutions such as the HUNGARIAN ACADEMY OF

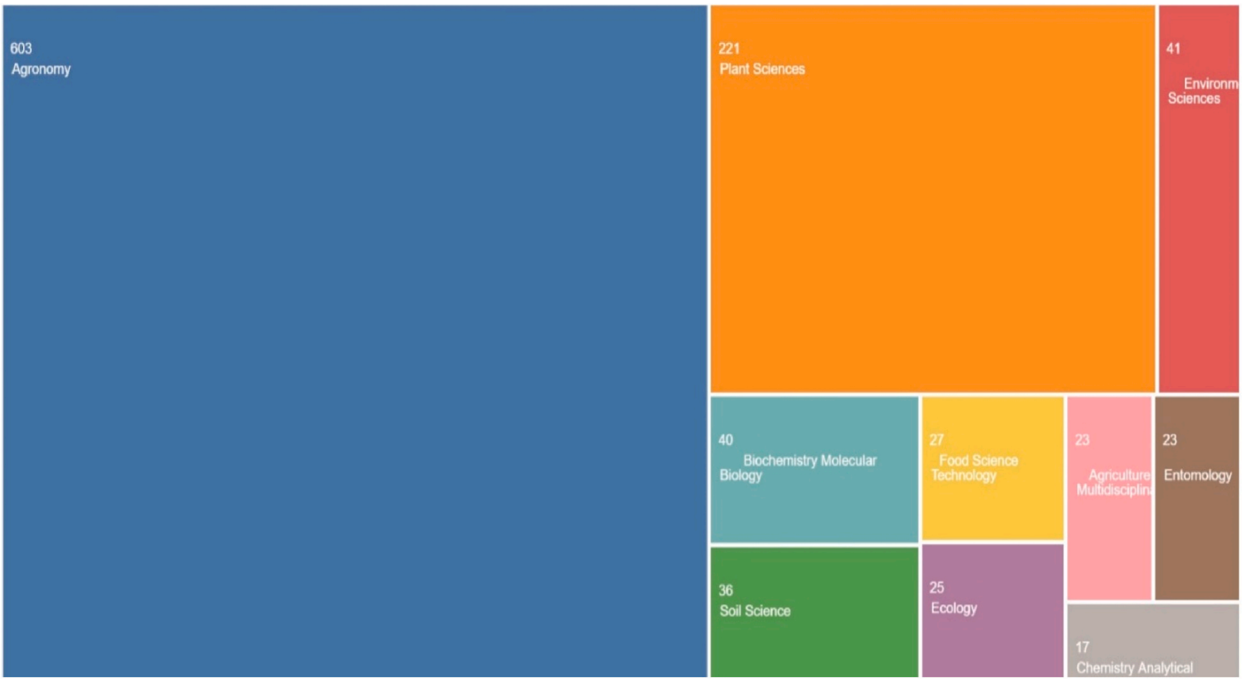

Fig. 4. Distribution of publications by WoS categories (subject areas) on MRH between 1975 and 2022. MRH: Maize, Research and Hungary.

SCIENCE, SZENT ISTVAN UNIVERSITY, UNIVERSITY OF SZEGED and UNIVERSITY OF DEBRECEN exhibited great co-authorship based on the total link strength of 48, 30, 20 and 18 respectively (Table 1). Institutions have been clustered, representing research activity during the study period. The first purple cluster (1975–2005) indicates that institutions with high total strength of co-authorship links with other institutions included HUNGARIAN ACADEMY OF SCIENCE, the UNIVERSITY OF VESZPREM, RESEARCH INSTITUTE OF SOIL SCIENCE AND AGRICULTURE CHEMISTRY, CEREAL RESEARCH INSTITUTE. The second green cluster (2006–2017) shows that the UNIVERSITY OF DEBRECEN, UNIVERSITY OF PANNONIA AND SZENT ISTVAN UNIVERSITY had higher total strength of co-authorship links with other institutions. The last yellowish cluster indicates that the HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES, the CEREALS RESEARCH NON-PROFIT Ltd and the UNIVERSITY OF SZEGED have higher total strength of co-authorship links with other institutions (Fig. 5). Different institutions have established long-term research experiments to study several agronomic traits, practices, stresses and technologies. The University of Debrecen established Látókép Experimental Station in 1983, where long-term studies are conducted on maize, wheat, sunflower, soybean, canola, triticale, pea, sweet maize and potato [12].

Research institutions have greatly contributed to sustainable development through robust research and development, collaborations and partnerships, projects, consultations, interactions, and publications [35]. The role of universities has been observed through strong linkage with the industry through spin-off companies and commercialised innovations [36,37], which act as recent capitalist apparatus [38], National Innovation Systems and knowledge pool [38,39], training centres [40], instrument, skill and technique development [41]. However, the contribution of research institutions and universities differs among countries because of their different economic, historical context, social, political, cultural specificities, fields of study, and national major economic activity [37,42,43]. At times, low levels of interactions between basic research and applied research, low multidisciplinary research and limited cooperation between academic and non-academic institutions affects research output and publications [43]. Global ranking of countries with highest number of universities were: India (5,288), USA (3,216), Indonesia (2,595) compared to Hungary having only 64 universities [44].

3.3. Major Research areas on Maize in Hungary between 1975 and 2022

The network co-occurrence showed a total of 2870 all keywords and 1569 author keywords. The MRH was represented by different keywords. In terms of all author keywords, maize yield, stress, fertilisation, hybrids, pests and diseases appeared 97, 49, 47, 30, and 30 respectively representing all author keywords with the highest occurrence (Table 2). In terms of author keywords, maize yield, irrigation, pests and diseases, fertilisation and stress had highest occurrence of 39, 27, 19, 18 and 11 respectively (Table 3). Maize grain yield had the highest occurrence and total link strength value, indicating that all research efforts in Hungary regarding maize crop are geared towards increasing maize yield. Research studies have been clustered based on years and colours. The purple cluster before 2010 (1975–2010) shows that yield, hybrids, weeds, nutrients, chilling, variety, pests, diseases, stress, mycotoxins, tillage practices, biodiversity and competition had higher network co-occurrence of all author keywords. After 2010 between 2011 and 2018 (green cluster) shows that research keywords crop management, growth, development, fertilisation, nitrogen, nutrients, temperature, water use efficiency had higher network co-occurrence of all author keywords; the last yellowish coloured cluster 2019–2022 showed that the research keywords impact, climate change, adaptation, tolerance, carbon, precision had higher network co-occurrence of all author keywords (Fig. 6). Maize performance was represented by different terms such as quality, quantity, impact, production, productivity, stability, growth and development while agronomic practices included pest and disease management, crop management, weed management, tillage practices, and competition.

Maize yield (quantity and quality): On a global scale, maize production depends on a number of factors as studied by different researchers. Several agro-technical factors mainly; tillage practices, irrigation, plant density, previous crop, hybrid, nitrogen supply and plant years [45] supported maize growth and development. Supply of water through irrigation, hybrid selection, soil fertilisation offers great economic, environment and biological importance towards sustainable maize production [46,141]. Research and development in agriculture has impacted crop production and productivity in Hungary over the studied years [47]. Due to the fact that crop production is limited by a number of abiotic and biotic stresses, the need for intensive research has been emphasised to enable continued production amidst the prevailing plant stresses [48,49].

Hybrid: Maize yield was enhanced by nutrient supply and variety [50,51], recorded a 30% yield enhancement due to variety.

Table 1
The top 10 institutions conducting research on maize in Hungary between 1975 and 2022.

Institutions	Documents	Citations	Total link strength
Hungarian Academy of Science	210	3303	48
University of Debrecen	132	643	18
Szent Istvan University	60	865	30
Eotvos Lorand University	32	477	15
University of Pannonia	26	114	11
Budapest University Technology & Economics	21	720	7
University of Veszprem	19	64	6
University of Szeged	18	196	20
University of Kaposvar	15	129	2
Hungarian University of Agriculture & Life Sciences	11	4	7

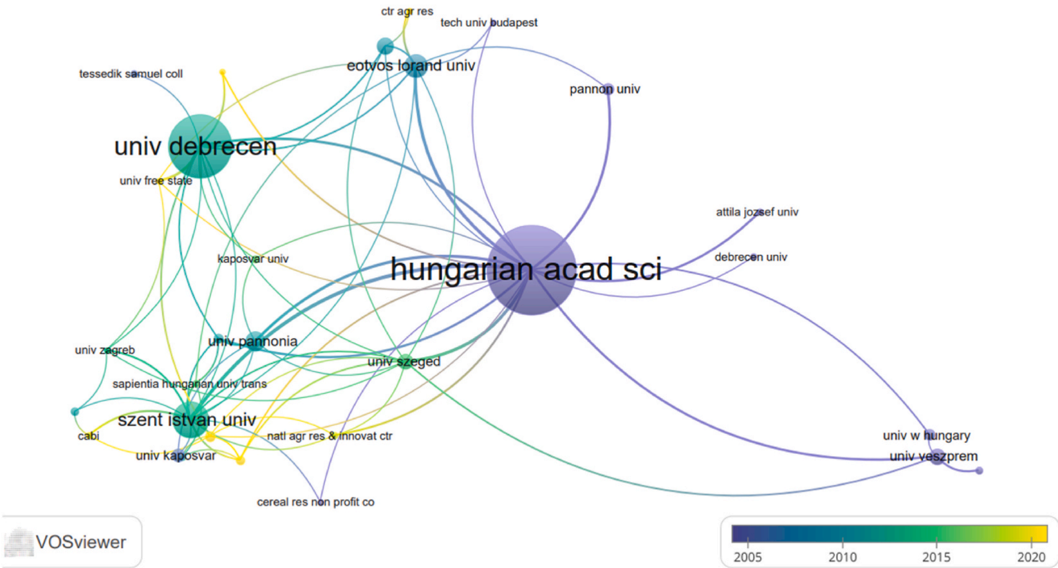

Fig. 5. Co-authorship links with other institutions on MRH between 1975 and 2022. MRH: Maize, Research and Hungary.

Table 2
Total link strength and co-occurrence of significant all author keywords on MRH literature between 1975 and 2022.

Keyword	Occurrences	Total link strength
Maize	301	322
Yield	97	118
Stress	49	87
Fertilization	47	63
Hybrids	30	52
Pests/diseases	30	41
Temperature	28	34
Nitrogen	23	37
Irrigation	22	41
Drought	20	37

Table 3
Total link strength and co-occurrence of most significant author keywords on MRH literature between 1975 and 2022.

Keyword	Occurrence	Total Link Strength
Maize/maize/*Zea mays*	236	118
Yield	39	25
Irrigation	27	24
Pests/diseases	19	7
Fertilization	18	22
Stress	11	11
Nitrogen	10	15
Drought	9	13
Climate change	8	11
Gene expression	8	8

Successful selection produced new inbred hybrids with fast drying abilities [52,53], genetic marker selection using isoenzymes, PCR and microsatellites [54,55], improvement of digestibility and internal silage maize qualities [56], improvement of crop population through genetics [57]. Mousavi et al. [58] proved the stability of FAO340 and FAO410 hybrids under NPK fertilisation in Hungary. KSC206, KSC704, KSC705 and KSC706 were identified as desirable single cross maize drought tolerant hybrids [139]. Szabó et al. [114] studied the nutrient specific response of seven maize hybrids namely: SY Minerva, DKC4792, Sushi, Fornad, Loupiac, P0217 and Armagnac. Four early-maturing sweet maize hybrids: 'Gyöngyhajnal', 'Nugát 72', 'Strongstar' and 'Sweetstar' commonly grown by Hungarian maize farmers have been investigated for cold stress tolerance [59]. Grain yield performance of P9494 and SY Afinity

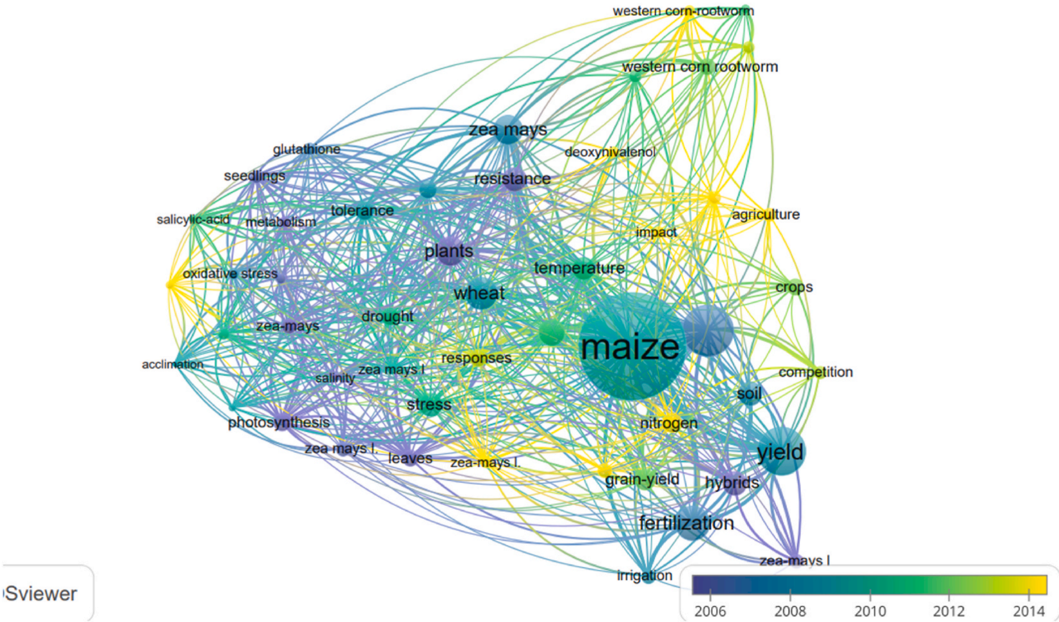

Fig. 6. Network co-occurrence of all author keywords on MRH literature between 1975 and 2022. MRH: Maize, Research and Hungary.

increased maize hybrids under NPK fertilisation [60]. Khatibi et al. [61] identified SC647 and KSC704 hybrids with high drought stress tolerance. Proper selection of hybrids improves conversion of nutrients thus avoiding nutrient loss. Thus, the adoption of hybrid based agro-technical solutions provided yield protection associated with climate change [62]. Hybrid breeding and selection has boosted maize yield and provided farmers with the best productive genotypes that tolerate and adopt under different abiotic and biotic stresses in Hungary.

Pests and diseases: The major pests and diseases studied included; western corn rootworm, mycotoxins, *Diabrotica virgifera*, entomogenous nematode, *Heterorhabditis megidis*, beetles, *Aspergillus flavus*, weeds. Maize yield (quantity and quality) is greatly affected by pests, diseases, pathogens and weeds [63]. However, increased pesticide use has led to severe adverse effects on health, pollution, and death of decomposers, natural enemies and pollinators [64]. Pests and diseases improvement breeding programmes [49,65] have emerged as a viable solution to control pests and diseases, thereby enhancing maize yields. Two paths were studied to improve western corn rootworm resistant hybrids to include conventional methods and transgenic technology [66]. Scientists, researchers, policy makers and organisations across Europe have focused research and policies on reduction of pesticide use and implementation of integrated pest management and production in a sustainable modern farming manner [67,68].

Climate change (Drought and temperature): Weather and climate change exert tremendous pressure on important production and environmental resources globally, leading to food insecurity and poverty [69]. Recently, Europe has been greatly hit by drought spells causing temperature increase and reduced precipitation [70,71], which has led to economic losses among farmers. Hungary has shown vulnerability to climate change impacts manifested by frequent drought impacting agricultural production [72]. European countries are expected to face prolonged drought spells in the future and Hungary is no exception [70]. Gálos et al. [73], predicted the prevalence of drought events in Hungary during the closing years of the 21st century. Several studies have noted a need for strong climate adaptation, resilient and tolerant measures to guard against the severe impacts of drought disruption and economic losses in the near future [48,74,75]. Amidst strong drought spells in Hungary, there has been remarkable increased crop production and yields specifically of cereal production (maize and wheat) in recent seasons [76]. Increased crop production in Hungary was attributed to: adoption of improved farming techniques such as precision agriculture techniques and systems; cultivation of appropriate types of crops; appropriate land use methods and water scheduling, and last effectiveness and integrated pest and disease management [77]. This justifies the importance of research in agriculture as it promotes and sustains crop production under unfavourable climatic conditions such as drought, high temperatures and cold stress.

Stress: Major plant biotic stresses include micro-organisms such as viruses, protozoa, bacteria, and fungi while abiotic stresses include extreme plant environmental changes, namely salinity, drought, heat, UV radiation, frost, nutrient deficiency and toxicity [78,79]. These plant stresses reduce plant yields both qualitatively and quantitatively [80,81]. Chilling tolerance is a major plant stress in Hungary [82–85]. Chilling tolerance was of great importance for silage and grain hybrids (FAO 200–240) and (FAO 150–190) according to Pintér, [86]. Stress tolerance research improved seed quality [87]. Limited plant growth conditions and requirements such as water, light intensity, plant nutrients, temperature and water have stressed maize production through limiting plant growth and development [88–90]. Robust research is a major requirement to address different maize growth stresses with the aim of improving yields.

Fertilisation: Deterioration of Hungarian soil properties has greatly affected maize production [62]. One of the effective ways to increase maize yields is through nutrient replenishment [91,92]. Use of NPK fertiliser improves maize yield during short crop growth periods [16]. Fertiliser development leads to precise control of nutrient supply to plants, and controlled environmental pollution [93, 94]. Maize monoculture effect was reduced by 50% due to fertilisation [95], macro-element fertilisation [96] enhanced crop yields. Nitrogen, i.e. the most important plant nutrient enhances maize yield [97–99]. However, balanced supply of plant nutrients at different growth stages is crucial to achieve required yields [100–102]. Nitrogen fertilisation enhances protein synthesis [103], and increases maize yield [104]. Fertilisation partially compensates unfavourable agro-technical plant requirements [105].

Irrigation: Occurrence of water deficit periods during crop growth and development periods leads to varying yield responses depending on the sensitivity of crops at each growth period. Supplemental irrigation at critical crop growth stages improves yield and water productivity, [106]. Irrigation in maize achieves higher water use efficiency compared to non-irrigated maize [107]. Precision dripping irrigation systems improve soil ventilation and moisture [108]. Water Use Efficiency improves the allocation, distribution, and conveyance of water to plants [109] and leads to reduced loss of water by use of proper irrigation methods for example drip irrigation systems that easily deliver water to exact points where it is required. Average water application efficiencies: surface irrigation systems (60–90%); sprinkler irrigation (65–90%); drip irrigation (75–90%) [110]. Uniform distribution of irrigation water in the field enhances water use efficiency as a result of precise irrigation delivery systems. Maize field irrigation management requires proper water quantification technologies that enhance irrigation scheduling for effectiveness and economic use of limited water supply. Recently, the irrigated areas have expanded globally but the amount of irrigation water is scarce, thereby necessitating the adoption of water use efficiency technologies which help maximise crop yields under deficit irrigation conditions.

Water management: Crop production by resource poor farmers depends on climatic changes and changing rainfall patterns, risking water insecurities leading to poverty. Maximisation of crop quality and quantity yields was efficient and enhanced by water use [47]. Maximisation of water use efficiency requires water conservation and crop growth promotion through optimisation of proper tillage timing, planting, soil fertilisation, pest and disease control, [111]. In order to boost sustainable maize yields, there is a great need to improve water management and water use efficiency in rainfed agricultural zones [112]. Crop water use efficiency depends on several factors, namely: water holding capacity (WHC), crop physiological characteristics, meteorological (climatic) conditions, genotype and agronomic practices [113]. Improvement of water use efficiency for maize can be achieved through application of nitrogenous fertilisers for areas that receive enough rainfall or irrigation [114]. Nutrient supply management improves water use efficiency. Ogola et al. [115] noted that application of nitrogen improved water use efficiency of maize; Gao et al. [116] noted that silicon as a plant nutrient improved water use efficiency in maize plants under water stress through the reduction of leaf transpiration and water flow rate in xylem vessels. Consequently, the need to strengthen the capacity of rural communities to adopt and disseminate different agricultural water management technologies arises.

3.4. *Researchers/authors that have contributed to MRH literature between 1975 and 2022. MRH: Maize, Research and Hungary*

In total, 1822 authors had published at least one document on MRH topics (Fig. 7). The highest number of documents published by an author was 63 documents and the lowest number was one (1) document. The top five authors with high number of documents published were: Nagy, J (63), Pinter, I (48), Kovacs, G (42), Paldi, E (23) and Barnabas, B (22) (Table 4). A total of 25 authors published more than 5 documents, thus contributed 68.9% of the MRH literature based on Web of Science between 1975 and 2022. The highly cited articles studied areas of chilling stress, photosynthetic activity, crop rotation and fertilisation, drought tolerance, cadmium stress, nitrogen use, hybrids, pollen and anther embryogenesis (Table 5) thus justifying the studied keywords.

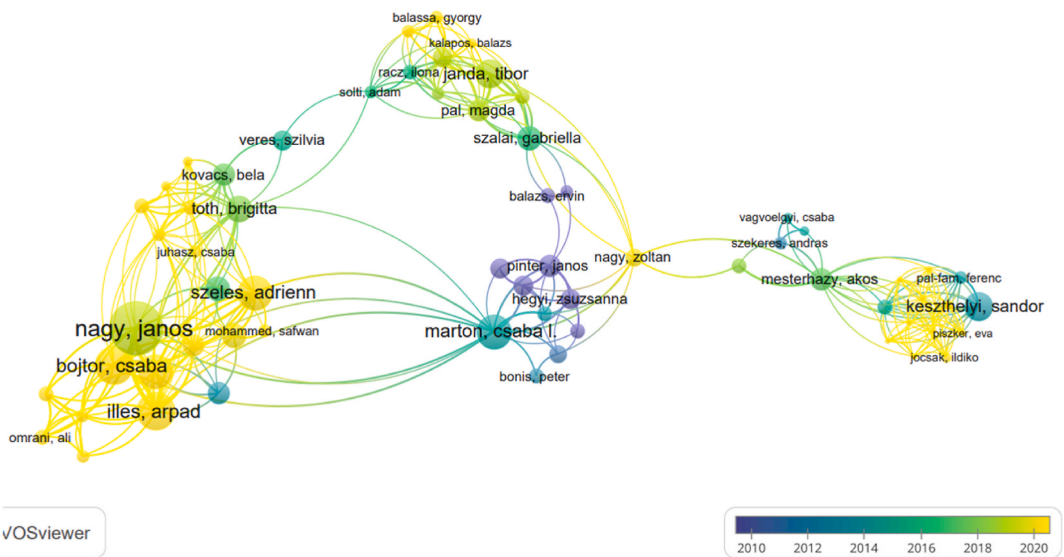

Fig. 7. Linkage between co-authorship and authorship on MRH literature 1975 to 2022. MRH: Maize, Research and Hungary.

Table 4
The top 10 authors and citations on MRH literature between 1975 and 2022. MRH: Maize, Research and Hungary.

Author	Documents	Total link strength
Nagy, J.	63	54
Pinter, I.	48	3
Kovacs, G.	42	11
Paldi, E	23	39
Barnabas, B	22	10
Szalai, G	21	36
Toth, B.	19	15
Janda, T	19	36
Bojtor, C.	15	52
Illes, A.	15	52

There was a direct relationship established between the authors and research institutions. The top authors with high number of documents published on MRH were attached to the top research institutions. The four authors with the highest total link strength to include: Nagy Janos, Bojtor Csaba, Illes Arpad, Mousavi Seyed Mohammad Nasir belong to University of Debrecen which was among the top MRH institutions. This implies that the performance of a research institution depends on researchers/scientists/authors capable of supervising and managing maize research and experiments. Transdisciplinary approaches play an important role towards achievement of SDG's, as researchers link science and society [117]. Scientists have studied soil impact on biodiversity, food security, climate change, clean, safe and fresh water availability, and energy conservation under various research programs, soil journals and conferences contributing land-related SDG's [118]. Researchers, scientists, faculty members and students at different institutions connect, participate and contribute to global science development and maintenance of the standards of research institutions and universities [119]. Limited publications and knowledge sharing was attributed to; poor working methods, psychological behaviours, negative attitudes by academicians thus reducing academic commitment and performance [120].

3.5. Overall research and production gaps and future prospects

Yield gap denoted by yield potential and the actual yield difference [130] serves as evidence for research interventions to improve maize yields. Globally, farmers have managed to produce only 50% of the estimated maize yield potential [131], implying that there is a greater potential to improve maize yields. Exploring maize yield and production gaps essentially increases grain yields contributing to the required future food supply amidst a growing population competing for limited available resources. Production gaps attributed to inefficient maize crop management practices by farmers constrain yield improvements [132]. Marton et al. [133] noted that global production gaps will be escalated by climatic changes characterised by increased temperatures across regions. Europe hit by extreme water shortages and weather changes would heavily affect crop yields, yield variability causing reduction in cultivable land under traditional crops [134]. Irrigation increases maize yields by 19% if applied at critical development stage [135] but due to ignorance and shortage of irrigation water, farmers cannot maximise production. Maize production gaps in Hungary have been majorly attributed to the land reforms that led to complex social and economic effects, as well as heat stress [136]. This calls for research interventions to innovate methods which farmers can easily adopt and implement on their farms. It is crucial to foster research collaboration and knowledge integration among soil science, plant science, agro-ecology, agronomy, and extension services. This multidisciplinary approach creates an agricultural system which is ecologically informed, blending traditional agricultural wisdom and ecological knowledge. Such cooperation is fundamental in enhancing grain yields [137]. Authors believe that the future of maize production in Hungary is intricately tied to ongoing research efforts to address challenges posed by evolving agricultural landscapes and climate change. Future research will revolutionise maize cultivation, focusing on sustainable practices, climate-resilient varieties, and precision agriculture technologies. As climate change alters weather patterns and elevates the frequency of extreme events, research initiatives are anticipated to develop maize varieties resilient to drought and cold stress, pests, and diseases. These enhanced cultivars will ensure stable yields as well as reduced reliance on chemical inputs, promoting environmentally friendly farming. Additionally, advancements in precision agriculture, facilitated by technologies such as drones and satellite imagery, will optimise irrigation, fertilisation, and pest management. This precision-driven approach will enhance resource efficiency, conserving water and minimising environmental impact while maximizing maize yields. Furthermore, research will delve into soil health management, emphasising sustainable practices like cover cropping and reduced tillage, which enhance soil fertility and structure, crucial for robust maize growth. Collaborative efforts between researchers, farmers, and policymakers are envisioned to promote knowledge exchange and the adoption of innovative farming techniques. Moreover, research will play a pivotal role in the development of agroecological practices, integrating traditional knowledge with modern science to create resilient farming systems. Through interdisciplinary studies encompassing genetics, agronomy, and environmental sciences, Hungary's maize production sector is poised for a transformative phase. Research-driven solutions are expected not only to mitigate challenges but also to foster a sustainable, productive, and environmentally conscious maize farming future in Hungary. However, the authors think the following measures can be adopted as key future research areas which have not been fully studied in Hungary but are critical in addressing yield and nutritional potential gaps of maize as an important cereal.

Table 5
Top 10 highest cited articles on MRH literature between 1975 and 2022. MRH: Maize, Research and Hungary.

Author	Publication title	Average citations per year	Total citations
[121]	Hydroponic treatment with salicylic acid decreases the effects of chilling injury in maize (*Zea mays* L.) plants.	15.4	385
[122]	Treatment with salicylic acid decreases the effect of cadmium on photosynthesis in maize plants.	22	352
[95]	Effect of crop rotation and fertilization on maize and wheat yields and yield stability in a long-term experiment.	7.29	175
[123]	Exogenous salicylic acid increases polyamine content but may decrease drought tolerance in maize.	7.05	155
[124]	Physiological changes and defense mechanisms induced by cadmium stress in maize.	8.17	147
[125]	Cadmium stimulates the accumulation of salicylic acid and its putative precursors in maize (Zea mays) plants.	5.84	111
[126]	Effects of the available nitrogen on the photosynthetic activity and xanthophyll cycle pool of maize in field.	3.14	69
[127]	Colchicine, an efficient genome-doubling agent for maize (*Zea mays* L.) microspores cultured in anther.	2.52	63
[128]	Evaluating the effect of year and fertilization on the yield of mid ripening (FAO 400-499) maize hybrids.	2.18	37
[129]	Ultrastructural studies on pollen embryogenesis in maize (Zea mays L).	0.95	35

a) Variety selection and restrictions: Various types of maize exhibit unique traits, and the primary maize varieties vary from one region to another. Typically, the prevalent varieties in a specific area are well-suited for the local climate, soil, and ecological conditions. Due to climate change, environmental factors like water availability, soil quality, and climate patterns are altering in different regions. Consequently, the criteria for selecting maize varieties are also evolving. It is crucial to identify the future breeding direction of maize varieties through research in order to enhance their adaptability. This approach will optimise the beneficial effects of diverse maize varieties on yield in the face of changing climates across various regions.
b) Nutrient-Enhanced Maize: This is a remarkable agricultural advancement referring to a specialised variety of maize engineered to contain higher nutritional value. Food insecurity as a result of population explosion in the future requires both quantity and quality of food to combat hunger and nutritional deficiencies. Through innovative biotechnological methods, essential nutrients such as vitamins, minerals, and proteins can be enhanced in different maize varieties, addressing global malnutrition issues. Enriched with vital elements such as Vitamin A, iron, and zinc, such varieties will significantly improve the overall dietary intake of communities heavily reliant on maize-based diets, particularly in regions where malnutrition is prevalent. Such bio-fortified maize not only boosts the health and well-being of consumers but also plays a pivotal role in food security initiatives. By providing a sustainable solution to nutritional deficiencies, Nutrient-Enhanced Maize represents a promising stride towards combating global hunger and improving public health outcomes, thereby fostering healthier societies and promoting agricultural resilience in the face of evolving challenges.

4. Conclusions

This bibliographic study was performed to comprehensively assess the trend of maize research in Hungary between 1975 and 2022. There was a significant positive increase in the number of published documents. Both academic and non-academic institutions were involved in maize research with Hungarian Academy of Science and University of Debrecen recording the highest number of publications. The major research areas were: increasing maize yield, hybrid development, pests and diseases, irrigation, stress, fertilisation (nitrogen), drought, temperature, gene expression and climate change. The increasing number of published documents directly relates to an increased response to addressing maize crop challenges through research in order to boost productivity.

Data availability statement

All the literature meta-data used in this review study is included in the article.

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CRediT authorship contribution statement

Brian Ssemugenze: Writing – review & editing, Writing – original draft. **Akasairi Ocwa:** Writing – review & editing, Visualization, Validation. **Csaba Bojtor:** Writing – review & editing. **Árpád Illés:** Writing – review & editing. **Joseph Esimu:** Data curation, Conceptualization. **János Nagy:** Supervision, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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