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# PATENT LANDSCAPE REVIEW ON MODERN OIL PALM CLIMATIC ADAPTATION STRATEGIES: GAPS AND OPPORTUNITIES

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## ABSTRACT

*Climate change is evolving at both a speed and magnitude that necessitates oil palm adaptation through innovation. This study both tracks and synthesises climate change adaptation patents applicable to oil palm cultivation. Oil palm patent applications filed between 1960 and 2022 were analysed through a network analysis, and compared to patents applied for soybean, rapeseed, and sunflower sectors. Findings indicate that the existing pool of oilseed adaptation patents is small. Oil palm adaptation patents primarily focus on and are concentrated on novel process innovation in plant breeding and biomass recycling techniques. Soybean patents cover both modern plant breeding technologies and plant varieties. By comparison, patent references to oil palm adaptation patents are fewer in number. These findings reveal a mismatch between oil palm adaptation requirements and technological availability knowledge. The oil palm research and development community are encouraged to better secure and disseminate intellectual property (IP) rights in order to inform adaptation diffusion and planning.*

**Keywords:** adaptation strategy, climate change, intellectual property, oil palm, technology

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## INTRODUCTION

Adaptation innovation is critical in reducing the long-term threat of climate change in so far as it threatens oil palm's productivity advantage. The global average temperature is expected to rise by 1.5°C between 2030 and 2052 (IPCC, 2018), and the chance of occurrence is increasing over time (WMO, 2023). In such climatology, plantings of less adaptable oil palm cultivars experience increased mortality rates (Paterson, 2020). Climate change has also been linked to an increase in the occurrence of *Ganoderma boninense* fungus, causing basal stem rot disease (Abubakar *et al.*, 2022). Even when failing to account for extreme climatic shocks, 1°C localised warming could cause as much as 10% drop in oil palm yield (Sarkar *et al.*, 2020). The compounding of such climate-related factors could reduce oil palm productivity significantly.

National and international policies that prohibit deforestation also necessitate adaptation technology for increasing oil palm production without expanding into forest areas. Under Presidential Instruction No. 5 of 2019, issuing new licenses to clear primary forests and peatlands in Indonesia has been permanently halted (Cabinet Secretariat of the Republic of Indonesia, 2019). The Malaysian Sustainable Palm Oil Certification Scheme (MSPO), which all oil palm growers are required to comply, forbids the inclusion of oil palm land converted from forest after December 31, 2019. Furthermore, the Deforestation-Free Regulation of the European Union prohibits the importation of palm oil products derived from forest land cleared after December 31, 2020. Productive adaptation technology is desirable under the deforestation-free supply chain regime to enable greater production from existing lands, thus reducing the demand for new oil palm plantations.

Using global patent data, this study tracks innovations that can help oil palm and three

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other major oilseeds adapt to climate change. This comparison is motivated by the expectation that temperatures will rise above the oilseed threshold, threatening yield stability (Ahmad *et al.*, 2021). Oil palm yield losses will be more severe than in other major oilseeds (Makowski *et al.*, 2020). Moreover, the global vegetable oil and fat market is highly competitive, with soybean, rapeseed, and sunflower oils competing with the cost per hectare of oil palm production (Zimmer, 2016). Technological advancements (*e.g.*, in farm mechanisation) is one common initiative that has been undertaken to improve the efficiency of annual oilseeds and to address their adaptation to climate change. Adaptation strategies for oil palm cultivation, in comparison, have primarily relied on conventional agricultural practices (Abubakar *et al.*, 2021). General awareness concerning available oil palm adaptation technologies appears to be lacking. This study attempts to fill that knowledge gap.

This study adds to the body of knowledge in three ways. This is the first study to consider modern adaptation strategies for oil palm. Prior efforts have focused on common agricultural practices that can assist climate-resilient agricultural practices. Secondly, this study identifies technological hotspots in climate change adaptation. Climate policy could be modified to accelerate or to take advantage of their emergence. Thirdly, and most importantly, this research identifies the technological gaps that exist between oil palm and other oilseeds. This has important implications for the oil palm research and development (R&D). Closing the R&D gap is an important step toward achieving climate-resilient, competitive oil palm production.

Patent systems raise technology awareness in the context of climate change (Behles, 2009). When required or desirable technology becomes objectively available and widely disseminated, technology diffusion becomes most efficient and useful. It should serve to at least discourage "techno-optimism", the belief that technology will become more widely available to address climate change (McLaren and Markusson, 2020). Efficient diffusion should also aim to prevent postponement of R&D and adaptation investment, which frequently occur under the assumption that the longer the wait, the better (or cheaper) the technology. This study thus informs adaptation diffusion by revealing the present state of technologies for oil palm adaption.

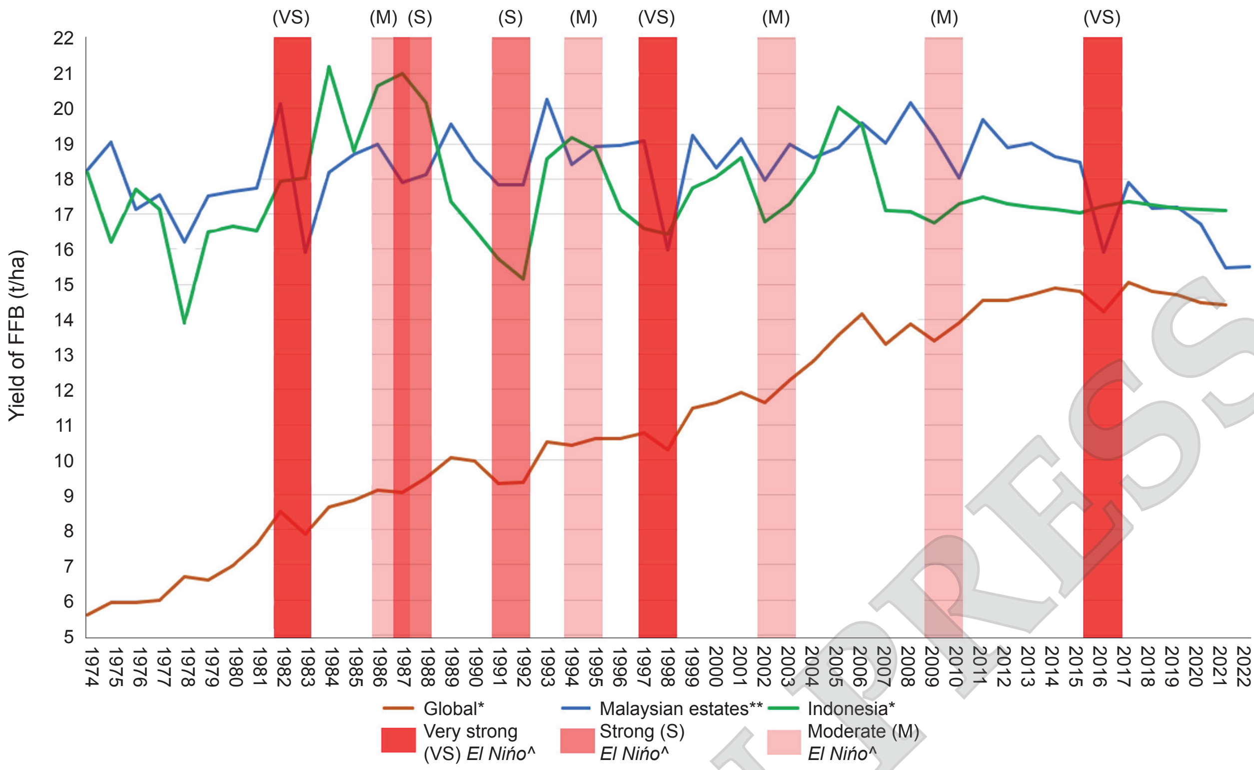
## LITERATURE REVIEW

Extreme climate events have an impact on oil palm productivity. Oil palm, like other oilseed crops, is susceptible to heat stress (Ahmad *et al.*, 2021). *Figure 1* depicts the series of yield declines that correspond with various *El Niño* events for Indonesia, Malaysia and the wider world. *El Niño* weather events are associated with increased temperatures and decreased rainfall, resulting in a high level of heat and water stress (Meehl *et al.*, 2000). Most moderate *El Niño* events resulted in a decrease in oil palm yield when compared to the previous year. Strong and very strong *El Niño* events resulted in steeper declines. In addition to hot and dry weather events, higher than normal rainfall occurred during *La Niña* events in other years (Li *et al.*, 2022).

Despite these erratic global patterns, global oil palm productivity continued to rise. However, the major producing countries, Indonesia and Malaysia, demonstrated a contra trend. Their oil palm productivity has declined to levels last seen in the 1970s. Adaptation must be prioritised to ensure great resilience to both water scarcity and excess for oil palms.

Conservation of soil and water assists oil palm trees in their economic lifecycle to achieve productivity. They are carried out to aid in water infiltration and retention during prolonged droughts and soil aeration during high-intensity rainfall. Plantation tillage is preferred for oil palm (re)planting over intensive tillage, which depletes soil organic matter through aerobic mineralisation (Suresh, 2013). Oil palm trunks are logged and left to decompose during the replanting stage to improve soil fertility through carbon and mineral recycling (Uke *et al.*, 2021). Intercropping leguminous cover crops (LCC) during plantation establishment reduces soil erosion and increases nitrogen availability until the canopy of the trees reaches full shade (Agamuthu and Broughton, 1985). Mulch utilising empty fruit bunches and pruned fronds improves soil structure and fertility as well as water retention capacity (Rudolf *et al.*, 2021). The use of treated palm oil mill effluent as an organic fertiliser can produce positive results due to improvements in soil moisture regime and soil structure, as well as nutrient addition and a reduction in soil and nutrient erosion (Amelia *et al.*, 2017). Silt pits collect runoff and return nutrients into the soil (Moradi *et al.*, 2012).

There are some tradeoffs when using natural soil and water conservation measures. Some expense is incurred when purchasing and establishing LCC (Lemessa and Wakjira, 2015). However, such soft grasses are preferred by cattle that graze within young plantations when livestock integration is used as a climate change adaptation approach (Grinnell *et al.*, 2022). Due to logistical constraints, biomass-based soil nutrient recovery is usually limited to (sub)plantations near the source of availability rather than plantation-wide application (Comte *et al.*, 2013). When the carbon to nitrogen ratio is too high, improper management can turn solid biomass into a pest breeding ground (Pulingam *et al.*, 2022). Furthermore, biomass is increasing in commercial value. Empty fruit bunches, for example, are now




Notes: Underestimation of oil palm yields is prevented because harvested area is the denominator. **Malaysian estates refer to private and government/state agency estates, including those with organised smallholders with area of 100 acres and above. Estates are generally more productive than smallholding farms. ^*El Niño* weather events are defined as five consecutive overlapping three-month periods with temperatures at or above the +0.5ºC anomaly. *La Niña* weather events are not depicted.

Sources: Authors' illustration: * - FAO (2023); ** - MPOB (2021, 2022, 2023); ^ - Golden Gate Weather Services (2023) data.

*Figure 1. Oil palm yields declined in the face of* El Niño *events.*

sold to produce a variety of energy, chemical and material goods (Rubinsin *et al.*, 2020). Biomass will become scarcer for *in situ* resource recycling, which will also require time to attain the desired results.

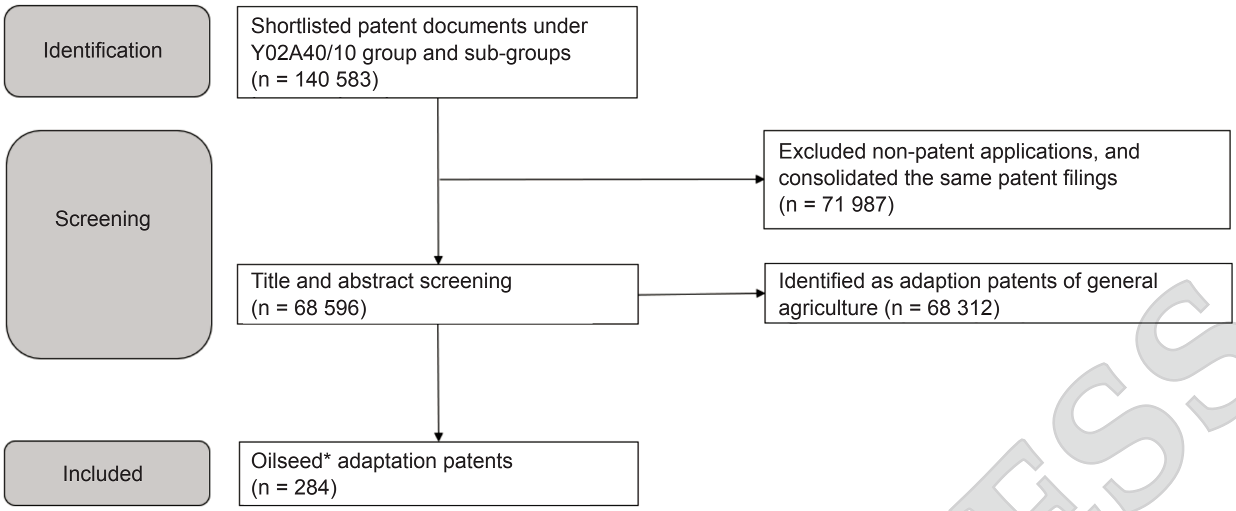
Given these considerations, external inputs for scaling climate change adaptation are required, and this begins with knowing their availability. Thus far, seed technology has received the most attention. Cultivar selection and plant breeding for abiotic and biotic stress tolerance, such as drought, flooding, soil salination, pest and disease resistance, has begun (Suresh, 2013). Understanding the responses of climate-resilient oil palm to a wide range of climate-triggered soil and nutrition uptake conditions is ongoing (Rival, 2017). Through patent analysis, Wang and Coleman (2016) discovered novel varieties suited for growing oil palm in subtropical regions, but not for assisting existing oil palm producing areas to adapt to the changing climate. Little is also known about technologies that could help oil palm become more productive under variable climatic conditions. This study thus identifies oil palm adaptation patents, where the applications represent the early success of innovations, to inform adaptation planning.

## METHODOLOGY

### Data

This study's patent data was obtained from the Espacenet database. *Figure 2* illustrates the data acquisition process. Developed by the European Patent Office, it is the most comprehensive open data source (Li *et al.*, 2013), providing the most robust patent information (Jürgens and Herrero-Solana, 2015). The European Patent Office recently launched an algorithm-based classification scheme that has expanded from climate change mitigation to adaptation technologies (Angelucci *et al.*, 2018).

This study used the Cooperative Patent Classification (CPC) system to shortlist patent documents that fall under the 'technologies for adaptation to climate change in agriculture' (Y02A40/10) group and its various sub-groups. The period between 1960 and 2022 was analysed. The shortlisting process produced 140 583 patents of various document types. Only patent applications were considered since they provide the most up-to-date information on innovation. Other documents were excluded. To avoid double counting,




Note: * - Includes oil palm, soybean, rapeseed and sunflower.

*Figure 2. Data acquisition process of the study.*

applications for the same patent filed in different countries were consolidated. Finally, for the patent analysis, this study considered only patent applications that provided all necessary information in title and abstract.

As a result, this study's dataset contains 68 596 patent applications. These patent documents were classified as general agriculture, as well those pertaining to the four major oilseeds, *viz.* oil palm, soybeans, rapeseed and sunflower.

Patent sub-group classifications, which linked patents to technological characteristics, were extracted from the dataset. When compared to the methodology which uses unsupervised keywords in patent documents, patent classification validated on a regular basis in the Espacenet is considered relatively reliable. It has a standard error rate of less than 7% (Angelucci *et al.*, 2018).

**Empirical Methods**

The empirical approach of this study involves three stages. In the first stage, the trajectories of climate change adaptation patents for oil palm, soybean, rapeseed and sunflower were compared with those utilised in general agriculture. A more detailed analysis distinguished the relative growth trends in the four major oilseed sectors.

In the second stage, using disaggregation, the agglomerative hierarchical clustering method was used to analyse patent classifications for identifying structures in oilseed patent networks. It merged the most similar oilseed clusters.

A series of *n-1* clustering decisions is used to combine nodes into a hierarchical structure. Each node (patent sub-group classification) begins as a single cluster, and similar nodes are subsequently merged into a new cluster. This clustering process is repeated until only a single cluster remains. As such, any member of a cluster can trace its membership back to its origin. The visual result is a dendrogram, which becomes increasingly unwieldy with larger applications (Hair *et al.*, 2013). In other words, the agglomerative hierarchical clustering method has plausible validity with a small dataset (Marešová *et al.*, 2022).

In this study, cluster similarity was determined by the greatest distance between two nodes using the complete-linkage clustering algorithm. All nodes in a cluster were connected to each other at maximum distances through the following Equation (1):

$$D(r, s) = \text{Max} \{ d(i, j) \} \quad (1)$$

Where object $i$ is in cluster $r$ and object $j$ is cluster $s$.

The distance between every possible object pair $(i,j)$ was computed, where object $i$ is in cluster $r$ and object $j$ is in cluster $s$ and the maximum value of these distances is said to be the distance between clusters $r$ and $s$. The value of the longest link between two clusters represents the distance between them. At each stage of hierarchical clustering, the clusters $r$ and $s$ with the highest $D(r, s)$ were merged.

The complete-linkage clustering algorithm generates the most compact clustering solutions by joining the maximum distance of dissimilar clusters (Baeza-Yates, 1992). It is also appropriate for a variety of clustering applications (Jain and Dubes, 1988).

The number of clusters most representative of the data structure was determined in this study using an agglomeration coefficient. An agglomerative coefficient measures the dissimilarity of an object to the first cluster it joins, divided by the dissimilarity of the final merger in the cluster analysis, averaged across all samples. Small (or large) coefficients indicate that homogeneous (or different) clusters are being merged. When the agglomeration coefficient changes significantly, the prior cluster solution is chosen. This type of rule has been shown to make reasonably accurate decisions about the number of clusters (Milligan and Cooper, 1985).

Finally, patent citations were examined to ascertain any knowledge transfer from earlier to subsequent patents. A forward citation references a subsequent patent. As a result, forward citations ascribe the technological foundation of patented inventions (Jaffe and De Rassenfosse, 2019) and the technological impact of patents (Pianta and Sirilli, 1996). The F-value was measured as Equation (2) with the null hypothesis that variance in forward patent citations is equal among oilseed crops.

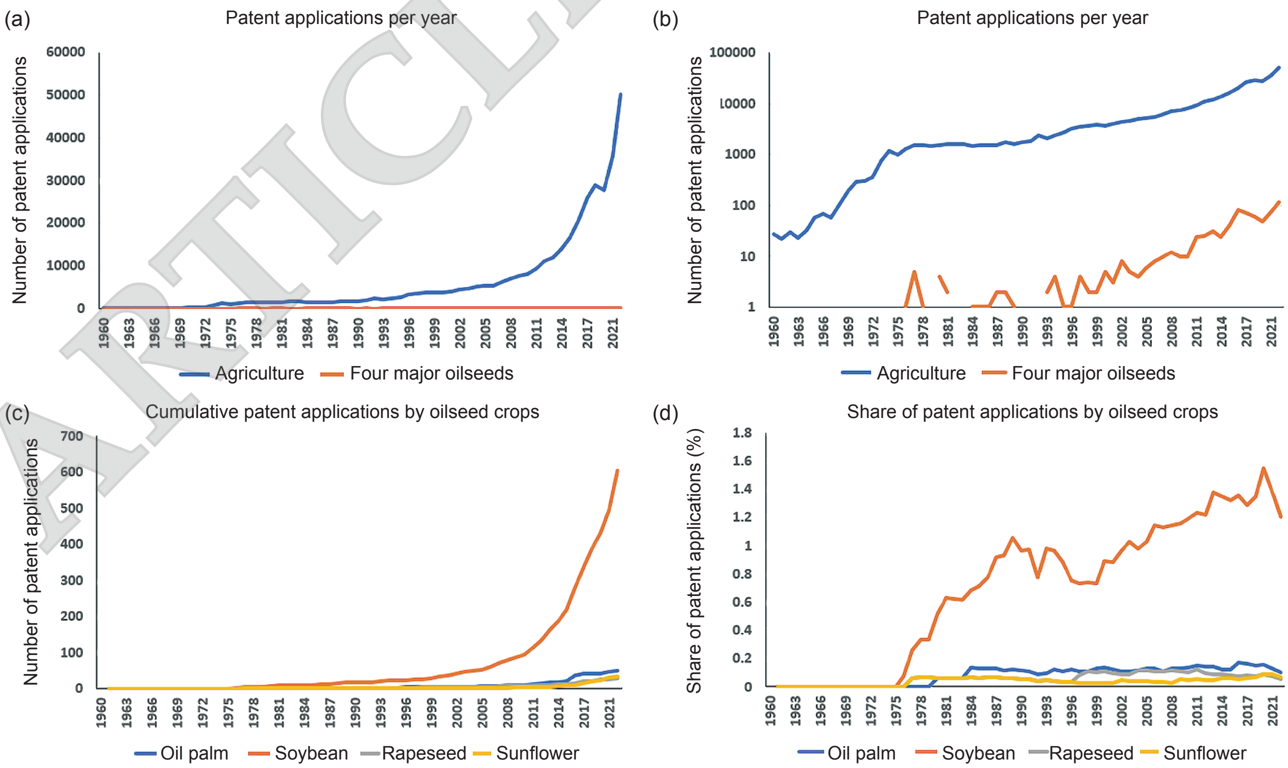
*F-value = between-groups variance / within-group variance* (2)

## RESULTS

The dataset was aggregated for agricultural adaptation technologies and then disaggregated into oilseeds for exploratory purposes. Agricultural patents for climate change adaptation have increased exponentially since 1960 (*Figure 3a*). Given the small number of oilseed patents, the number of patent applications was plotted on a log scale to show the rate of change. It was established that oilseed innovation in the same technological class had emerged spasmodically since the mid-1970s (*Figure 3b*). Twenty years later such innovation had evolved into a steady growth pattern. Oilseed patents grew at a faster rate than agricultural patents due to their lower starting point. This does not, however, imply that the proportion of oilseed patents within the agricultural adaptation patent pool has risen exponentially.

The disaggregated dataset contained 284 oilseed adaptation patents, with 31 oil palm patents, 14 sunflower patents, 214 soybean patents and 25 rapeseed patents. Soybean technologies have accounted for three-quarters of all oilseed inventions in patent applications since 1960 (*Figure 3c*). The other three oilseeds have significantly fewer adaptation patents in absolute terms. Similarly, soybean adaptation technology patents maintained a higher overall proportion throughout the study period (*Figure 3d*). Its annual share increased, while the other oilseed patent applications fluctuated around a much lower base.

Because of the small number of oilseed patents discovered, prior to further analysis, a validation process was carried out by referring to previous patent analyses of oilseed crops. Miao and Guo (2015) investigated patents for genetically modified (GM) soybeans, while Wang and Coleman (2016) researched palm oil production and waste treatment patents. These previous studies made no mention of climate (including climate adaptation) patents. This is still the case in Ji *et al.* (2019), who investigated soybean or rapeseed patents, and Wibowo *et al.*




*Figures 3. Aggregated and disaggregated patents in the dataset.*

(2019), who investigated palm oil patents. It is most likely that this has occurred due to the relative insignificance of oilseed adaptation technology in the patent pools used in those studies. As a result, this study's limited dataset was deemed valid, necessitating the employment of the agglomerative hierarchical clustering technique.

**Clusters of Oilseed Adaptation Patents**

The clustering analysis in this study considered sub-group classifications found in at least 10% of the observations (patents) for an oilseed. The minimum criterion used to identify eligible sub-group classifications for the analysis was three for oil palm patents, two for sunflower patents, 21 for soybean patents, and three for rapeseed patents. The qualified sub-group classifications are summarised in *Table 1*.

*Figures 4* show the results of the complete-linkage clustering method. The horizontal axes represent the distance between each cluster. The vertical dashed lines denote the agglomerative criterion for selecting the number of clusters. For oilseed patents, two clusters were identified. Each with an optimal number of sub-group classifications ranged from 2 to 9. Sub-group classifications that merge sooner are more alike than those that merge later.

A cluster of enabling technologies for improved plant breeding emerged among climate change adaptation patents in both the oil palm and soybean industries. In the case of oil palm (*Figure 4a*), the cluster is led by patents underlying the 'mutation or genetic engineering; deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) concerning genetic engineering, vectors, with agronomic (input) traits' (C12N15/8261), the 'peptides having more than 20 amino acids; gastrins; somatostatins; melanotropins; derivatives thereof from plants' (C07K14/415), and the 'oligonucleotides characterised by their use for polymorphic or mutational markers' (C12Q2600/156) sub-groups. The focus of these patents is to use nucleic acid sequencing to predict and control (shell and membrane) phenotypes in oil palm. They aim to improve plant breeding by incorporating desirable agronomic traits.

In terms of soybean (*Figure 4b*), the enabling technologies cluster is characterised by patents classified for the 'measuring or testing processes involving enzymes, nucleic acids or microorganisms; compositions therefore; processes of preparing such compositions for plants, fungi or algae' (C12Q1/6895), the 'angiosperms, seeds' (A01H5/04), 'angiosperms, glycine max (soybean)' (A01H6/542), and the 'oligonucleotides characterised by their use for plant traits' (C12Q2600/13) sub-groups. Many of these patents describe a transgenic soybean with an event that expresses the DNA molecules produced by transgenic DNA insertion into a soybean plant's genome. They also developed techniques for detecting these transgenic events. Methods which enhance gene composition and selection for soybean were also improved. They aim to strengthen resistance to plant parasitic (*i.e.*, root knot and cyst) nematodes and insects (*i.e.*, aphid). Innovations were also developed to improve drought and herbicide tolerance in soybean.

Further, another soybean cluster (*Figure 4b*) shows that soybean climate change adaptation technology fundamentally centres on improving varieties with agronomic (input) traits. Many of these patents were primarily obtained because of 'genetic modifications' (Y02A40/146). Plant breeding through 'mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, with agronomic (input) traits for insect' (C12N15/8286), 'herbicide' (C12N15/8274), and 'nematode resistance' (C12N15/8285) has remained a major goal for soybean crop improvement. Some new soybean varieties have been patented for their "overall" benefits rather than for any specific trait. These traits include improved oil composition and "healthier" properties.

Besides such plant breeding innovation, a cluster of biofertiliser processing technologies predominated among both oil palm and rapeseed climate change adaptation patents. In the case of oil palm (*Figure 2a*), the cluster is dominated by 'fertilisers of biological origin' (Y02A40/20), 'technologies for solid waste management through bio-organic fraction processing; production of fertilisers from the organic fraction of waste or refuse' (Y02W30/40), 'technologies relating to chemical industry from the feedstock being materials of biological origin' (Y02P20/145), and 'fertilisers from solid waste from mechanical processing of material' (C05F5/002). Given that these sub-groups are closely related and significant, the oil palm cluster clearly focuses on recycling both the solid and liquid waste generated on and off-farm. Patents underlying this cluster prescribe preparation methods, treatment processes, and conversion and extraction procedures for producing biofertilisers from palm biomass and biogas.

The biofertiliser processing cluster for the rapeseed industry (*Figure 4c*) has sub-group classifications that are like those of oil palm, with one exception: Patents in this cluster are primarily aimed at extracting oil from hulled rapeseed, with secondary descriptors as to how to convert rapeseed meal and cake into organic fertilisers.

Another rapeseed cluster centres on general agricultural adaptation innovation such as planting methods and irrigation technologies. Similarly, the sunflower clusters (*Figure 4d*) do not refer to any specific climate change adaptation strategy. They were likely constrained by the large variation among the small number of observations.

**TABLE 1. QUALIFIED SUB-GROUP CLASSIFICATIONS OF CLIMATE CHANGE ADAPTATION PATENTS OF OILSEEDS**

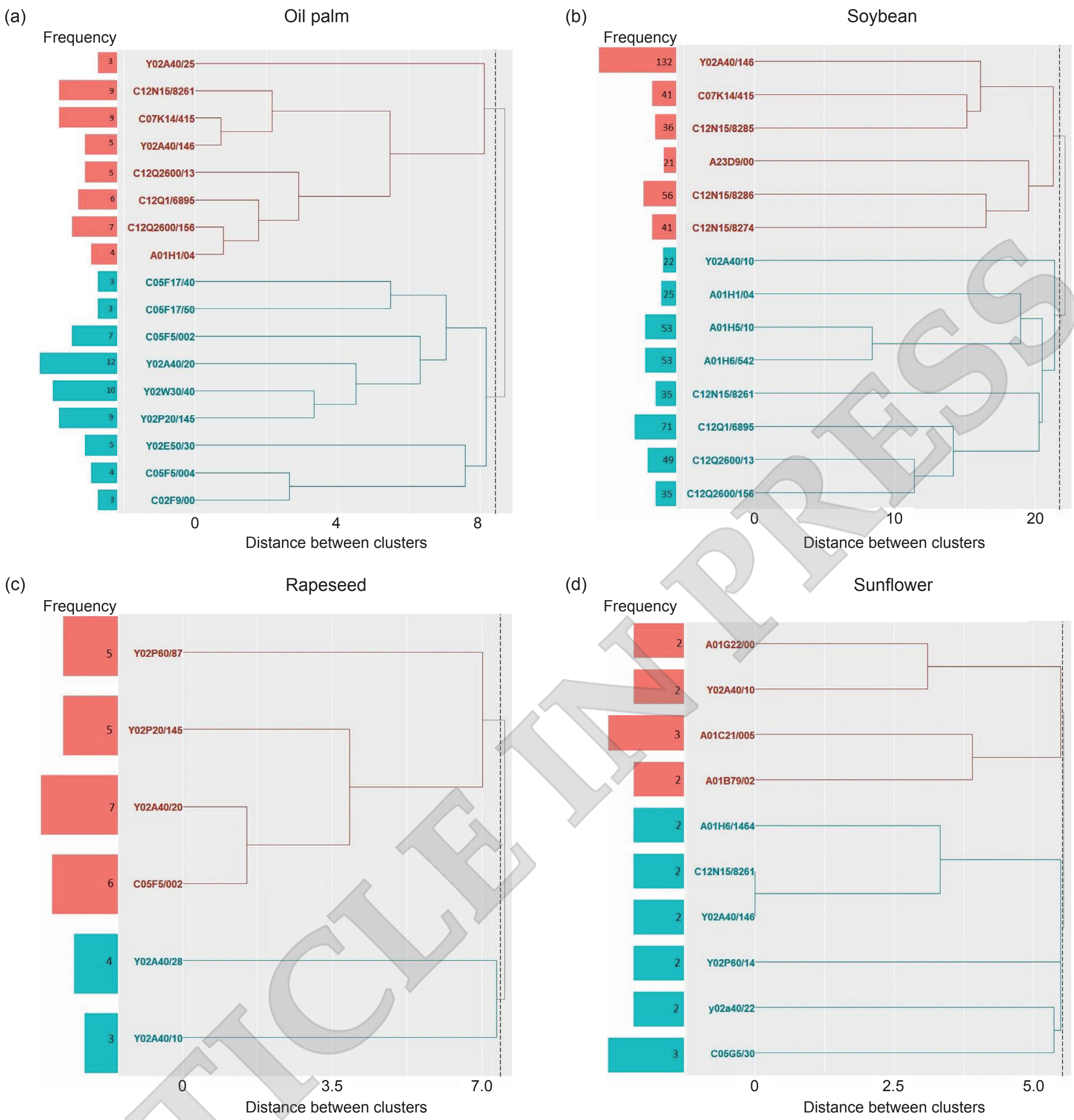
| Sub-group | Description |
|---|---|
| A01B79/02 | Methods for working soil combined with other agricultural processing |
| A01C21/005 | Methods of fertilising following a specific plan |
| A01G22/00 | Cultivation of specific crops or plants not otherwise provided for |
| A01H1/04 | Processes for modifying genotypes involving genotypic or phenotypic markers; methods of using phenotypic markers for selection |
| A01H5/10 | Angiosperms, seeds |
| A01H6/1464 | Angiosperms, *Helianthus annuus* (sunflower) |
| A01H6/542 | Angiosperms, *Glycine max* (soybean) |
| A23D9/00 | Other edible oils or fats |
| C02F9/00 | Multistage treatment of water, wastewater, or sewage |
| C05F17/40 | Preparation of fertilisers characterised by biological or biochemical treatment steps for treatment of liquids or slurries |
| C05F17/50 | Preparation of fertilisers characterised by biological or biochemical treatment steps treatments combining two or more different biological or biochemical treatments |
| C05F5/002 | Fertilisers from solid waste from mechanical processing of material |
| C05F5/004 | Fertilisers from liquid waste from mechanical processing of material |
| C05G5/30 | Fertilisers characterised by their form of layered or coated |
| C07K14/415 | Peptides having more than 20 amino acids; gastrins; somatostatins; melanotropins; derivatives thereof from plants |
| C12N15/8261 | Mutation or genetic engineering; deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) concerning genetic engineering, vectors, with agronomic (input) traits |
| C12N15/8274 | Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, with agronomic (input) traits for herbicide resistance |
| C12N15/8285 | Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, with agronomic (input) traits for nematode resistance |
| C12N15/8286 | Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, with agronomic (input) traits for insect resistance |
| C12Q1/6895 | Measuring or testing processes involving enzymes, nucleic acids, or microorganisms; compositions therefor; processes of preparing such compositions for plants, fungi, or algae |
| C12Q2600/13 | Oligonucleotides characterised by their use for plant traits |
| C12Q2600/156 | Oligonucleotides characterised by their use for polymorphic or mutational markers |
| Y02A40/10 | Adaptation technologies in agriculture |
| Y02A40/146 | Adaptation technologies in agriculture: Genetically modified plants |
| Y02A40/20 | Adaptation technologies in agriculture: Fertilisers of biological origin |
| Y02A40/22 | Adaptation technologies in agriculture: Improved land use |
| Y02A40/25 | Adaptation technologies in agriculture: Greenhouse technology |
| Y02A40/28 | Adaptation technologies in agriculture: Specially adapted for farming |
| Y02E50/30 | Technologies to produce fuel from waste |
| Y02P20/145 | Technologies relating to chemical industry from the feedstock being materials of biological origin |
| Y02P60/14 | Technologies relating to agriculture for saving energy |
| Y02P60/87 | Technologies relating to agriculture for re-use of by-products of food processing for fodder production |
| Y02W30/40 | Technologies for solid waste management through bio-organic fraction processing; production of fertilisers from the organic fraction of waste or refuse |

Source: Espacenet (2023).



**Patents as a Knowledge Base for Subsequent Innovation**

According to the F-test statistic ($p$>0.05) in *Figure 5*, the mean difference between forward citations of oilseeds is statistically insignificant. However, the distribution and mean scores of the four oilseed industries differ markedly. Half of the oil palm patents received one citation based on the box length, which represents the interquartile range and contains 50% of its forward citations. On average, five subsequent patents cited each oil palm




Note: Refer to *Table 1* for the description of patent sub-group classifications.

*Figures 4. Clusters of climate change adaptation patents of oilseed crops, 1960-2022.*

patent. One patent for a zero-discharge treatment system for palm oil mill effluent attracted five times the average number of forward citations.

Soybean and rapeseed patents had similar box lengths, beginning with a zero citation. The upward whiskers protruding from the box indicate that they have a higher number of forward citations than the oil palm industry. On average, approximately 34 subsequent patents cited soybean patents and 12 subsequent patents cited rapeseed patents. As evidenced by the number of forward patent counts that exceeded the whisker, 16 (7.5%) soybean patents were highly cited, with 10 involving soybean transgenic events and the remainder focusing on plant varieties with improved agronomic traits (*i.e.*, insect resistance and herbicide tolerance). The only rapeseed patent (4.0%) with a high number of forward citations invented a rapeseed variety with a lower saturated fatty acid content.

## DISCUSSION

Climate change threatens the productivity of oil palm trees. Rising to this challenge requires not only the maintenance of existing (good) agricultural

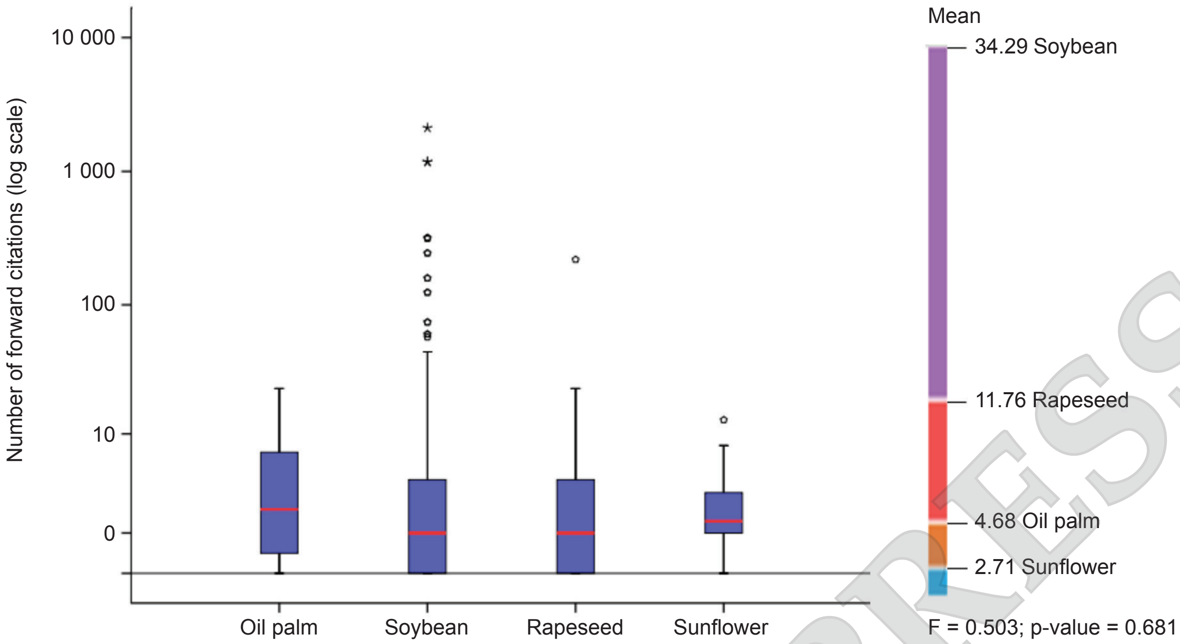



*Figure 5. Forward citations in climate change adaptation patents of oilseed crops.*

practices, but also the acceleration of innovation to provide strategies for coping with increasingly difficult production conditions. Understanding options for adaptation becomes necessary to ensure climate-resilient oil palm production. In this study, expanding the oil palm knowledge base was compared to adaptation innovation developed for other oilseed seeds, specifically soybean, rapeseed and sunflower.

Findings of this study reveal that the number of oil palm climatic adaptation patents is low both in absolute terms and relative to agricultural patents. This observation holds true for all the oilseed crops studied. Oilseed innovation clusters are also highly concentrated. Oil palm adaptation patents tend to focus on plant breeding and biofertiliser processing technologies. The latter was also central to rapeseed, while the former was found in the soybean sector. Another dominant cluster in soybean focuses on plant varieties with improved agronomic (particularly input) traits. Further, the reference of oil palm adaptation patents by subsequent patents was relatively limited.

The findings suggest that trade secrecy is prevalent in the major oilseed sectors. Non-disclosure is arguably the most vulnerable form of intellectual property (IP) (Lewis, 2018). Nonetheless, other oilseed sectors are also notable for their unwillingness to share information about R&D advances. Access to R&D tools, for example, has become increasingly limited in the canola sector over time (Galushko and Oikonomou, 2007; Galushko *et al.*, 2010). In business-as-usual scenarios, these R&D output strategies may be appropriate. The discovery of a small patent pool in the global patent system reveals an important knowledge gap in identifying climate-resilient technologies. Without disseminating their availability, widespread adoption is impossible. This is especially important for the palm oil industry, because, as previously stated, oil palm yields in major producing countries have fallen to a critical level.

The findings of this study point to three specific issues that require attention to boost innovation and subsequently productivity in climate change adaptation for oil palm production. These issues are relevant to the reorganisation of oil palm R&D, management by both the public and private sectors, as well as the associated opportunity to reorient innovation and commercialisation efforts.

Firstly, patents for oil palm adaptation innovation are scarce. Oil palm R&D is relatively advanced in comparison to other agricultural sectors that suffer from a lack of local inventive capability (Govindaraju and Wong 2011). Similarly, the palm oil industry has relatively high expenditure on R&D. In Malaysia, a tax on crude palm oil and palm kernel oil production is collected to support the Malaysian Palm Oil Board's (MPOB) R&D initiatives. Innovations of the MPOB are published annually in the Journal of Oil Palm Research (*e.g.*, Parveez *et al.*, 2022) and disseminated through annual Transfer of Technology Seminars (TOT). Other channels are also used. Established plantation companies also invest extensively in in-house and collaborative R&D programmes (Tey *et al.*, 2020).

Given such available financial and technical resources, priorities should be set to increase IP awareness, facilitate IP filing, and provide market incentives to encourage patenting and/or knowledge transfer. Such interventions should involve all R&D communities, including oil palm-specific research institutions, universities, government-linked companies, and private companies.

Secondly, product innovation resulting from oil palm process innovation has not been patented. Existing oil palm research literature (*e.g.*, Martin *et al.*, 2022) has also primarily focused on modern breeding tools. The patent database contains a significant lack of improved oil palm varieties and farm inputs, indicating a long-standing underrepresentation of oil palm technological development for sustainability progress within the patenting regime and the knowledge base.

With the growing demand for adaptability and ever more productive planting materials, a strong case exists for focusing on contemporary adaptation strategies produced by state-of-the-art techniques. The questions as to whether the institutional function of R&D organisations should be expanded to include patent filing facilitation, whether all such adaptive solutions are capable of being patented or, indeed whether they should be, is beyond the scope of this paper. However, the technological foundation required to drive innovation productivity is clear: In the absence of IP, innovation and adaptation productivity can only be accomplished through individual access to and the capacity to acquire contemporary innovate ideologies and technological knowledge. This is exemplified by the fact that the proprietary R&D outputs of integrated plantation enterprises deliberately favour their business welfare, undermining the potential of generating wider benefits for the industry.

Reinforcing that point, finally, the scarcity of subsequent oil palm patents seems directly correlated with its small patent base. As discussed previously, this does not always imply a lack of innovation. Patentable innovation may not be filed where a need for confidentiality is deemed desirable. Patent documents reveal detailed technical knowledge and are only valid in the country or region in which they are registered. However, it does indicate the opportunity cost associated with knowledge and technology growth. Patents can be and are often sought in each jurisdiction where protection is required, and the certainty of patent protection drives commercialisation (Wagner and Wakeman, 2016).

In the case of oil palm, opportunities remain to seek IP rights over inventions and build a knowledge base for future innovation. In agricultural biotechnology, for example, American IP rights have motivated private investment in applied research that has been built on a foundation of public basic research (Wright and Shih, 2010).

Given the discussion above, a shortcoming of the methodology used in this study must be acknowledged. Patent publications represent only one type of R&D output. A considerable pool of modern adaptation technologies for oilseed production have not been, or cannot, be patentable. Examples are numerous but include novel oil palm varieties resulting from genomic innovation for identifying markers or genes controlling polygenic traits such as low height, pest and disease resistance, high yield, and climate resilience (Low *et al.*, 2017).

Future research should take account of modern adaptation technologies beyond those discussed here. The broadest contemporary knowledge is required for the effective implementation of cultural practices. An initiative which consolidates public and private sector R&D outputs that are both responsive to a variety of climate and sustainability challenges seems the logical next step. Moreover, understanding the state of innovation appears critical for facilitating oil palm R&D that is better suited to a dynamic environment. It should also facilitate a comparative analysis of adaptation innovation in other oilseed industries, thus providing a better understanding of the R&D gaps.

## CONCLUSION

The importance of a knowledge base in informing diffusion for both the scale and speed of adaptation strategies in oil palm production is growing. However, this study reveals a scarcity of oil palm patents directed towards climate change adaptation. Existing oil palm patents are generally concerned with process innovation and show a lack of product innovation. In contrast, soybean adaptation patents encompass both process and product innovation. Critically, oil palm adaptation patents are associated with fewer subsequent patents than soybean adaptation patents. As a result, this study reveals a mismatch between the need for oil palm adaptation and technological availability knowledge. Oil palm R&D institutions should embrace a better considered IP paradigm in order to lay the groundwork for informing technology diffusion, which is critical in accelerating oil palm adaptation to climate change.

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