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Farming the Future: Advanced Techniques in Modern Agriculture

Volume I

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PREFACE

Welcome to "Farming the Future: Advanced Techniques in Modern Agriculture" This book represents a journey into the transformative landscape of contemporary farming practices. As our world grapples with burgeoning populations, shifting climates, and environmental challenges, the need for sustainable and efficient agricultural methods has never been more pressing.

In these pages, we explore the cutting-edge techniques and technologies that are reshaping the agricultural sector. From precision farming and hydroponics to genetic engineering and AI-driven analytics, each chapter delves into innovations that promise to enhance yields, conserve resources, and mitigate environmental impact.

The evolution of agriculture is not merely a matter of technological advancement but a profound shift in how we steward the Earth's resources responsibly for future generations. It is about harnessing innovation to ensure food security without compromising the integrity of our ecosystems.

Throughout this book, experts and pioneers in the field share their insights, challenges, and successes, offering a comprehensive guide to those who are passionate about shaping the future of farming. Whether you are a seasoned agriculturalist, a researcher, a policymaker, or simply curious about the future of food production, "Farming the Future" aims to inform, inspire, and catalyze meaningful change.

As we embark on this exploration together, let us envision a future where agriculture not only sustains but thrives—a future where innovation and sustainability go hand in hand to feed a growing planet while safeguarding its natural resources.

Thank you for joining us on this journey into the heart of modern agriculture.

Editors

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Introduction:

Insecticides mixtures are usually used in the field to enhance the spectrum of control when multiple pests are attacking simultaneously. They are also recommended to increase the efficacy of control against a single pest, or to delay the development of insecticide resistance or to combat current resistance in a pest species. Using mixtures as a countermeasure for resistance management in insect-pests has been advocated by several workers but without good experimental evidence. There is already wide-spread use of pesticide mixtures associated with greenhouse and nursery operations world-wide, partly because combinations of selective pesticides may be required in order to deal with the arthropod pest population complex present in the crop (Helyer, 2002; Ahmad, 2004; Cloyd, 2009; Khajehali *et al.*, 2009). Typically, two pesticides are mixed together; however, it has been demonstrated that three or more pesticides may be combined into a spray solution to target different insect and/or mite pests (Cloyd, 2009). Mixtures are available as pre-mixes from the pesticide companies or they are tank mixed by the farmers. Ideally, the insecticides having different modes of action are mixed on the assumption that they would complement the action of each other for killing the target pest. When two compounds are mixed, they can either be potentiating or additive or antagonistic in an insect species. These effects can be different on different insect species or strains depending upon their physiology and the mechanism(s) of resistance they have developed. If a mixture is potentiating, it is a useful tool in enhancing control efficacy and combating insecticide resistance. In this case, there may be potential for reducing the application rate of one or both components of the mixture. If a mixture is antagonistic, it should not be used, because it will reduce the efficiency of pest control and aggravate the resistance problem. The effects of two chemicals, when given together are often additive, that is, the combined effect of two chemicals is predictable based on the known toxicity of both compounds. No specific interactions occur (1 + 1 = 2). Incompatibility is a physical condition by which pesticides do not mix properly to form a homogenous solution or suspension. Instead, flakes, crystals, or oily clumps form or there is a noticeable separation. Incompatibility may be due to the chemical and/or physical properties of the pesticides, impurities in the water, or the types of pesticide formulations being mixed together (Marer, 1988). In order to determine incompatibility (or compatibility) of a pesticide mixture, a 'jar test' should be conducted in which a representative sample of a pesticide mixture solution is collected in a glass jar and then allowed to remain stationary for approximately 15 minutes. If the solution is uniform or homogenous, then the pesticides are compatible; however, if there is clumping or separation, then the pesticides are not compatible with each other (Marer, 1988).

The combined effect of the administration of two compounds may be greater than the sum of the two effects; this is called synergism. The synergist piperonyl butoxide is added to some insecticides to greatly increase their toxicity to insects (1+ 1 = 10). The term "synergism" is used for cases where two compounds together show a more concerted activity than that predicted from the some of their individual activities. Often one component is not toxic or far less active than the counterpart component at the dosage employed, but when combined with the latter markedly increases the activity and is called a "synergist". As related to insecticides, a synergist is used at high doses (for example, 5-10 times more than the insecticide) in many cases and the cost justifies its use in limited cases like natural pyrethrum. The effectiveness of an insecticide synergist is commonly expressed by the ratio of the LD_{50} of the insecticide with the synergist.

In 1940, it was found that sesame oil remarkably enhanced insecticidal activity of pyrethrum and later the active components were identified as sesamin and sesamolin, both being methylenedioxyphenyl (MDP) compounds (1,3- benzodioxole). Since then, many MDP compounds and other types of synergists have been introduced, but because of their cost and efficacy only a few synergists such as piperonyl butoxide (PB) and MGK 264 are of a practical use. Synergists are found in practically all aerosol bombs containing pyrethrins and allethrin which are used against flying household insects, and in other type formulations containing bioallethrin and tetramethrin. Many of the synthetic pyrethroids are not synergized by the common MDP pyrethrum synergists. However different types of synergists are still useful in insect toxicology to study mode of action, metabolism and resistance mechanism.

Types of synergism

There are several types of synergism:

1. Inhibition of mixed function oxidase enzymes
2. Inhibition of hydrolyzing enzymes
3. Release of hydrogen cyanide from organothiocyanates by glutathione S-transferases
4. Probably serving as alternative substrates
5. Two compounds interact with different sites of the target

1. Inhibition of oxidative metabolism

Inhibitors of oxidative metabolism of insecticides include diverse groups of compounds such as those containing the methylenedioxyphenyl (MDP) moiety, benzothidiazoles (e.g., WL 19,255), and imides (e.g. MGK 264). MDP compounds exert their synergism by inhibiting the mixed function oxidase system. Oxidation of methylenedioxy group by MFO first gives a hydroxylated intermediate, which takes two routes for further conversion. One is hydrolysis to give a catechol and formate as metabolites. Another is the production of a carbene, which complexes with P-450, resulting in the inhibition of MFO activity. The carbene may arise directly from MDP and degrades to catechol. These compounds can synergize not only pyrethrins , but also carbamates and other insecticides. When pest resistance is due to enhanced MFO metabolism, synergists often mask the resistance. However in case of organophosphates, the MDP compound inhibit both the oxidative detoxication and the conversion of P=S to P=O and the net result is often difficult to predict.

2. Inhibition of hydrolysis

Inhibitors of estrases or hydrolyzing enzymes include EPN (O-ethyl O-p-nitrophenyl phenylphosphonothioate), TOCP (tri-o-cresyl phosphate), DEF (S, S, S- tributyl phosphorotrithioate), triphenyl phosphate, and others. They enhance the insecticidal activity of melathion to resistant strains of insects. The combination of melathion with iprobenfos (a fungicide) was practically used in Japan on the green rice leafhopper resistant to melathion by inhibiting carboxyesterase.

Many insects have estrases hydrolyzing pyrethroids named pyrethroid esterases. Monocrotophos, profenofos, acetaphate, methidathion, some propynyl phosphonates and phenyl saligenin cyclic phosphate inhibit pyrethroid esterases, by which they increase the insecticidal activity. In contrast, oxidase inhibitors such as PB, SV-1, and MPP synergize considerably the toxicity of pyrethroids in Tribolium castaneum and Musca domestica. This implies that the predominant pathway for pyrethroid detoxication in insects, whether hydrolytic or oxidative, depends largely on the insect species.

3. Releasing hydrogen cyanide from organothiocyanates

Certain organothiocyanates are effective insecticides and act as synergists for carbamates and pyrethrins. These compounds release hydrogen cyanide by metabolism with glutathione S-transferases- glutathione system (GST-GSH), which contributes to the insecticidal activity.

RCH2SCN

4. Analog synergism

Synergists structurally related to the insecticides have shown their usefulness particularly with DDT. Compounds such as DMC (1,1-bis-(chlorophenyl) ethanol), a noninsecticidal structural analog of DDT, derivatives of diphenylamine and benzenesulfonamides, and several others, have been shown to increase the toxicity of DDT to DDT- resistant insects. The compound N,N-dibutyl(p-chlorobenzene) sulfonamide, designated as ‘WARE antiresistant’ (Pramex), had been marketed as a DDT synergist but attained only limited success.

5. Target site synergism

Two compounds interact with different sites of the target. Aryl N-methylcarbamates are used to control the green rice leafhopper, which develops cross resistance to them. Combination of an aryl N-methylcarbamate with an aryl N-propylcarbamate or with an oxadiazolone compound such as metoxadiazone overcomes the resistance. The resistance is due to the increased population having the modified acetylcholinesterase (AChE) insensitive to N-methylcarbamates. N- propylcarbamates or oxadiazolones are more inhibitory to the modified

AChE. Both components of combination interact with the preferred inhibition sites, thus achieving synergism.

6. Alternative substrates for detoxification

Some compounds may function as alternative substrates for detoxification, thus protecting the insecticides. Insecticides having MDP moiety in the molecules may synergize themselves (self-synergism). However, such ideas had only marginal success.

Examples

A combination of spinosad (spinosyn) and chlorpyrifos provided the best control of four species of *Liposcelis* (psocids) (Nayak and Daglish 2007). The binary mixtures of pyrethroids cypermethrin, α-cypermethrin, ζ-cypermethrin, bifenthrin, fenpropathrin, λ-cyhalothrin, and deltamethrin plus organophosphates ethion, profenofos, chlorpyrifos, quinalphos, acephate, methamidophos, methyl parathion, and triazophos were evaluated on putatively resistant field populations of*Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) from Pakistan using a leaf-dip bioassay. Ethion exhibited good potentiation with all the pyrethroids. Quinalphos potentiated cypermethrin, fenpropathrin, and λ-cyhalothrin but not bifenthrin. Acephate was potentiating with bifenthrin and fenpropathrin but antagonistic with ζ-cypermethrin. A potentiation effect was also found when methamidophos was mixed with bifenthrin and fenpropathrin (Ahmad, 2007). The evaluation of treatments in the control of *Spodoptera litura* (Fab.) on groundnut under glasshouse conditions revealed that combinations of microbial pesticides (nuclear polyhedrosis virus @ 1 x 107 PIBs ml"1, *Bacillus thuringiensis* subsp. *kurstaki* @ 1 x 10 spores ml"1 and *Beauveria bassiana* @ 1 x 107 spores ml"1) along with chemical insecticides (fenvelerate @ 0.005% and monocrotophos @ 0.025% i.e., half of the recommended dose) and microbial pesticides themselves were superior to either microbial pesticides or recommended rates of individual chemical insecticides alone. *B. thuringiensis* 1 x 107 spores ml + fenvelerate 0.005 per cent was proved as the best in respect of highest larval population reduction and lowest leaf damage (20.15 per cent). The highest pod yield (15.03 g pant"1) was recorded with the same treatment *(B. thuringiensis* 1 x 107 spores ml"1 + fenvelerate 0.005 percent) (table 1) (Jayanthi *et al.,* 2001).

In a laboratory study the interaction between two recently developed insecticides (pyridalyl and spinetoram) were combined at different mixing ratio in binary mixtures with eight compounds including 3 conventional insecticides (chlorpyrifos E, methomyl and deltamethrin), two IGRs (hexaflumuron and pyriproxyfen) and three synergists compounds (pepronyl butoxide, sesame oil and oleic acid) and investigated against *S. littoralis,* 4th instar larvae. Based on co-toxicity coefficient, both insecticides (pyridalyl and spinetoram) response positively when mixed with chlorpyrifos E and exhibited remarkable potentiation effect at most tested mixing ratio within 24 and 48h post treatment. On the other hand, slight synergism was only recorded for pyridalyl/pyriproxifen mixtures. In contrast, the three compounds (pbo, sesame oil and oleic acid) exhibited highly considerable synergism only in their binary miture with spinetoram (Razik *et al.,* 2013). Solami *et al.* (2014) Taking coeffective factor (C.F.) into consideration, the results revealed that the chemical insecticide actellic (pirimiphos-methyl) in combinations with spinosad, dudim and neem extract against the present mosquito larvae produced different levels of potentiation reflected by the inhibition of adult formation (table 2).

Table 1: Efficacy of microbial pesticides along with chemical insecticides on larval mortality, leaf damage by S. *litura* and pod yield ((Jayanthi *et al.*, 2001)

S. No.	Treatments	Larval mortality at 28 DAS, %	Leaf damage at 28 DAS, %	Pod yield (g plant $^{-1}$)
1	NPV alone	66.67 (54.99)	30.71 (33.65)	8.50
2	*B. thuringiensis* alone	80.00 (63.43)	23.33 (28.83)	11.00
3	*B. bassiana* alone	46.67 (43.08)	52.86 (46.61)	5.83
4	Fenvelerate alone (0.01%)	76.67 (61.22)	15.23 (22.90)	11.83
5	Monocrotophos alone (0.05%)	60.00 (50.77)	17.14 (24.38)	10.27
6	NPV + *B. thuringiensis*	90.00 (71.57)	22.85 (28.52)	9.17
7	NPV + *B. bassiana*	70.00 (57.00)	35.95 (36.81)	6.27
8	*B. thuringiensis* + *B. bassiana*	80.00 (63.43)	28.57 (32.27)	7.33
9	NPV + fenvelerate (0.005%)	83.33 (66.14)	27.86 (31.82)	8.43
10	*B. thuringiensis* + fenvelerate (0.005%)	100.00 (89.90)	11.90 (20.15)	15.03
11	*B. bassiana* + fenvelerate (0.005%)	73.33 (59.60)	24,76 (29.77)	7.03
12	NPV + monocrotophos (0.025%)	80.00 (63.93)	20.52 (26.68)	9.53
13	B. thuringiensis + monocrotophos (0.025%)	83.33 (66.40)	16.47 (23.91)	12.47
14	B. bassiana + monocrotophos (0.025%)	76.67 (61.22)	34.28 (35.79)	6.57
15	Control	0.00 (0.02)	77.86 (61.89)	5.50
	SEM	1.10	0.932	0.367
	CD (0.05)	3.05	2.701	1.062

DAS- Days after spraying, All treatments of NPV, *B. thuringiensis* and *B. bassiana* carried 1×10^7 PIBs ml^{-1}, 1×10^7 spores ml^{-1} and 1×10^7 spores ml^{-1}, respectively. Figures in parentheses are angular transformed values.

Table 2: The joint action of the conventional insecticide actellic with some non-conventional insecticides on the mosquito *A. aegypti*

Compound	**Concentrations**	**Cumulative mortality (%)**		**C.F.***	**Type of effect**
Mixtures	**Used (ppm)**	**Expected**	**Observed**		
actellic + spinosad					
LC25 + LC30	0.027 + 0.006	55	71	+ 29.1	(XX)
LC25 + LC40	0.027 + 0.0072	65	84	+ 22.6	(XX)
LC25 + LC50	0.027 + 0.009	75	91	+ 21.3	(XX)
actellic + dudim					
LC25 + IC30	0.027 + 0.00016	55	69	+ 25.4	(XX)
LC25 + IC40	0.027 + 0.00025	65	86	+ 32.3	(XX)
LC25 + IC50	0.027 + 0.00038	75	92	+ 22.7	(XX)
actellic + neem extract					
LC25 + IC2 30	0.027 + 26	55	67	+ 21.8	(XX)
LC25 + IC40	0.027 + 30	65	79	+ 21.5	(XX)
LC25 + IC50	0.027 + 35	75	95	+ 26.7	(XX)

*Coeffiective factor (Mansour *et al.*, 1966); (XX) Potentiation (Solami *et al.* (2014)

The joint action of destruxins and three botanical insecticides, rotenone (Rot), azadirachtin (Aza) and paeonolum (Pae) against the cotton aphid, *Aphis gossypii*, was bioassayed by Zou *et al.* (2012). In laboratory experiment, several synergistic groups of destruxins with botanical insecticides were found by means of Sun's Co-toxicity Coefficients (CTC) and Finney's Synergistic Coefficient (SC). The best synergistic effect was discovered in the ratio group Des/Rot 1/9 with the CTC or SC and LC50 values of 479.93 or 4.8 and 0.06 µg/mL, respectively. The second and third synergistic effects were recorded in the ratio groups Des/Rot 7/3 and 9/1. Although the ratio groups Des/Aza 6/4, Des/Pae 4/6, 3/7 and 2/8 indicated synergism by Sun's CTC, they were determined as additive actions by Finney's SC. Additive actions were also found in most of the ratio groups, but antagonism were recorded only in three ratio groups: Des/Pae 9/1, 7/3 and 6/4. In greenhouse tests, the highest mortality was 98.9% with the treatment Des/Rot 1/9 at 0.60 µg/mL, meanwhile, the treatments Des/Pae 4/6 and Des/Aza 6/4 had approximately 88% mortality (table 3).

Table 3: The LC-p equations, LC50s, CTCs and SCs of destruxins and rotenone (alone and in combination) against cotton aphids.

*Ratio group	Intercept	Slope	R	X^2	P	LC 50(μg/mL ,24h) (95%CI)	CTC	SC
10/0	3.3461	1.74103	0.9933	0.2610	0.9672	8.91(3.94-13.56)		
9/1	5.2003	0.7679	0.9957	0.1449	0.9860	0.55(0.24-0.88)	374.40	3.7
8/2	4.8969	0.8421	0.9988	0.0515	0.9969	1.33(0.72-2.01)	87.53	0.9
7/3	5.7584	1.0724	0.9994	0.0380	0.9981	0.19(0.13-0.28)	427.06	4.3
6/4	5.0343	1.6447	0.9911	0.9108	0.8228	0.95(0.69-1.22)	65.55	0.7
5/5	5.2913	1.0904	0.9980	0.1392	0.9867	0.54(0.37-0.77)	93.57	0.9
4/6	5.4039	1.2696	0.9904	0.8257	0.8433	0.48(0.36-0.67)	88.56	0.9
3/7	5.4169	1.0221	0.9961	0.2255	0.9734	0.39(0.26-0.57)	94.06	0.9
2/8	5.5559	1.0899	0.9942	0.4190	0.9363	0.31(0.19-0.43)	104.08	1.0
1/9	6.2325	0.9993	0.9932	0.3516	0.9501	0.06(0.03-0.09)	479.93	4.8
0/10	5.7492	1.2937	0.9852	0.8893	0.8280	0.26(0.17-0.37)	-	

*The ratio of destruxins/rotenone (Zou *et al.,* 2012)

Antagonism

The toxic effect of a chemical, A, agonist, can be reduced when given with another chemical, B, the antagonist. Antagonists, are often used as antidotes. There are several mechanisms of antagonism:

1) Functional antagonism: simple counterbalancing of the toxic effect (caffeine and phenobarbital).

2) chemical antagonism: antagonist reacts with the toxin to reduce toxicity (dimercaprol chelates toxic heavy metals such as As).

3) receptor antagonism: antagonist binds to receptor, (atropine with organophosphate insecticides).

4) dispositional antagonism: fate of the toxin is altered (cholestyramine can prevent absorption of organic chemicals by binding with them).

Examples

Ahmad (2007) profenofos was antagonistic with cypermethrin, bifenthrin, and λ-cyhalothrin. Similarly, bifenthrin + methyl parathion and deltamethrin + triazophos mixtures were antagonistic when tested on several populations of *b. tabaci*. Chlorpyrifos was antagonistic with cypermethrin but had an additive effect with fenpropathrin. Mixing together the miticide bifenazate with the organophosphate insecticide chlorpyrifos, and carbamate insecticides carbaryl, methomyl, and oxamyl decreased the efficacy of bifenazate against the twospotted spider mite indicating the occurrence of antagonism (Van Leeuwen *et al.* 2007; Khajehali *et al.* 2009). However, these effects may vary depending on the insect or mite strain (or strains), physiology, and resistance mechanisms present in the population (Ahmad 2004). profenofos, chlorpyrifos, quinalphos, and triazophos exhibited an antagonism with deltamethrin as well as cypermethrins for *Helicoverpa armigera* (Ahmad, 2004). Schleier and Peterson (2012). Examined the effect of nonester pyrethroid (etofenprox), type I (permethrin), and type II (cypermethrin) pyrethroid insecticides alone and in all combinations to *Drosophila melanogaster* Meigen. The combination of permethrin_etofenprox and permethrin_cypermethrin demonstrated antagonistic toxicity, while the combination of cypermethrin _ etofenprox demonstrated synergistic toxicity. The mixture of permethrin_cypermethrin_etofenprox demonstrated additive toxicity. The toxicity of permethrin_cypermethrin was significantly lower than the toxicity of cypermethrin alone, but the combination was not significantly different from permethrin alone. The toxicity of permethrin _cypermethrin_etofenprox was significantly greater than the toxicity of both permethrin and etofenprox alone, but it was significantly lower than cypermethrin alone. The mixture of permethrin and etofenprox was significantly less toxic than permethrin. The explanation for the decreased toxicity observed is most likely because of the competitive binding at the voltage-gated sodium channel, which is supported by physiological and biochemical studies of pyrethroids. Our results demonstrate that the assumption that the mixture toxicity of pyrethroids would be additive is not adequate for modeling the mixture toxicity of pyrethroids to insects (table 4).

Table 4: LC50 values, slope coefficient estimates for the logistic regression model, 95% confidence interval (CI) for the coefficient estimates, *P* value for the slope coefficients for the logistic quasi-binomial model, and the mixture toxicity

Chemical mixture	**LC 50(µg /cm²)**	**Coefficient estimate**	**95% CI coefficient estimate**	**P value**	**Mixture toxicity**
Permethrin	0.075	25.29	19.1-37.5	<0.0001	-
Etofenprox	0.1075	11.41	7.4-19.3	0.0066	-
Cypermethrin	0.0185	106.26	82.3-153.2	<0.0001	-
Permethrin +etofenprox	0.221	8.88	6.6-13.3	0.0002	Antagonistic
Permethrin +cypermethrin	0.081	24.38	16.4-40.1	0.0035	Antagonistic
Cypermethrin +etofenprox	0.019	102.37	77.6-150.9	0.0001	Synergistic
Permethrin cypermethrin +etofenprox	0.0345	56.95	44.3-81.8	<0.0001	Additive

(Schleier and Peterson, 2012)

Synergists in resistance management

Synergists have been used commercially for about 50 years and have contributed significantly to improve the efficacy of insecticides, particularly when problems of resistance have arisen. In the current article we review the nature, mode of action, role in resistance management, natural occurrence, and significance in research of insecticide synergists. These natural or synthetic chemicals, which increase the lethality and effectiveness of currently available insecticides, are by themselves considered nontoxic. The mode of action of the majority of synergists is to block the metabolic systems that would otherwise break down insecticide molecules. They interfere with the detoxication of insecticides through their action on polysubstrate monooxygenases (PSMOs) and other enzyme systems. The role of synergists in resistance management is related directly to an enzyme-inhibiting action, restoring the susceptibility of insects to the chemical, which would otherwise require higher levels of the toxicant for their control. For this reason synergists are considered straightforward tools for overcoming metabolic resistance, and can also delay the manifestation of resistance. However, the full potential of these compounds may not have been realized in resistance management. Synergists have an important role to play in the ongoing investigation of insecticide toxicity and mode of action and the nature of resistance mechanism. They also can be used in understanding the effects of other xenobiotics in non-target organisms. The search for and the need of new molecules capable of synergizing existing or new pesticides has reactivated the identification and characterization of secondary plant compounds possessing such activity. Plants do possess and utilize synergists to overcome the damage produced by phytophages. This has to be exploited in pest management programs.

Salama *et al.* (2002) performed an experiment. Larvae of the mosquito *Culex pipiens* were subjected to continuous laboratory selection with Baygon for 15 successive generations. This resistant strain was tested with some additives, piperonyl–butoxide, sesame oil and to investigate their synergistic or antagonistic effect. The use of sesame oil and piperonyl-butoxide considerably enhanced the toxicity of Baygon. The activity of each synergist was found to be concentration dependent. Results showed the possibility of using the piperonyl-butoxide and sesame oil as a synergist against a Baygon–resistant strain of *C. pipiens* (). The resistant strain was compared with the normal strain to determine the resistance level or the resistance ratio by the following equation:

$$\mathbf{R}.\mathrm{R} = \frac{\text{LC50 of the resistant strain}}{\text{LC50 of the normal strain}}$$

$$\mathrm{S.F.} = \frac{\text{LC50 of the insecticide alone}}{\text{LC50 of the insecticide/additive mixture}}$$

Table 5 indicates that the additions of 0.001, 0.005 & 0.01 % of piperonyl-butoxide to each concentration of Baygon caused a progressive decrease in LC50 values, i.e. increased larval mortality.

Table 5: Susceptibility of Baygon resistant strain of *Culex pipiens* larvae to Baygon and its combination with different concentrations of piperonyl-butoxide

Baygon Conc.(ppm)	**o.o**	**Piperonyl-butoxide concentration (%)**		
		0.001	0.005	0.01
5	--	-	5.0±0.33	18.3±0.67
6	--	10.0±0.58	31.7±0.88	35.0±0.58
10	--	26.7±0.88	50.0±1.16	60.0±1.16
20	o.o	40.5±0.56	65±1.50	80.0±1.53
30	5.3±0.8	70.0±1.16	88.3±1.45	95.0±1.0
50	25.0±162	90.0±0.67	--	--
60	46.7±0.88	--	--	--
80	72.7±1.73	--	--	--
LC50(ppm)	61.75	17.78	10.07	9.16
Slope function	1.49	2.31	2.65	2.21
R.R	308.7	88.9	50.35	45.8
S.F.	o.o	3.47	6.13	6.74

R.R resistance ratio, S.F synergistic factor, P.b piperonyl butoxide (Salama *et al.*, 2002)

Table 6 shows the synergistic effects of sesame oil when used in combination with Baygon insecticide against the Baygon-resistant *C. pipiens* larvae. There is a significant increase in larval mortality due to the combined effect of Baygon with sesame oil. The addition of increasing concentrations of sesame oil to Baygon greatly decreased the LC50 values, and hence increased Baygon's efficacy up to 10 times. The activity was clearly concentration dependent.

Table 6: Susceptibility of Baygon resistant strain of *Culex pipiens* larvae to Baygon and its combination with different concentrations of sesame oil

Baygon Conc.(ppm)	0.0	Sesame oil concentration (%)		
		1	2	4
5	--	20.0±0.58	31.7±1.33	36.7±0.33
10	--	46.7±0.33	66.7±1.20	75.0±1.16
20	0.0	60.0±1.0	82.0±1.0	88.3±0.88
30	5.3±0.8	76.7±0.88	90.0±0.58	96.7±0.68
50	25.0±162	90.0±0.67	--	--
60	46.7±0.88	--	--	--
80	72.7±1.73	--	--	--
$LC_{50(ppm)}$	61.75	13.04	7.78	6.20
Slope function	1.49	3.52	2.93	2.48
R.R.	308.7	65.2	38.9	31.0
S.F.	0.0	4.47	7.94	9.96

Salama *et al.*, 2002

The synergistic action of triphenyl phosphate (TPP) and piperonyl butoxicide (PB) on chlorfluazuron was studied in chlorfluazuron-susceptible and resistant larvae of diamondback moth, Plutella xylostella (L.). Synergistic ratios with TPP and PB were approximately 7 and 4, respectively, in two resistant strains, namely TL-resistant (TL-R) and BK-resistant (BK-R) strains. There was no synergism with TPP and PB in TL-susceptible (TL-S) strain, while there was up to 2-fold with TPP and 3-fold with PB in the BK-susceptible (BK-S) strain. From these results, it is likely that the enhanced degradation of chlorfluazuron by a TPP-sensitive enzyme system is responsible for chlorfluazuron resistance in diamondback moth. Teflubenzuron at a nontoxic level (<LC1) synergized chlorfluazuron in the resistant strains but did not in the susceptible strains. This result suggests that teflubenzuron interferes with chlorfluazuron degradation enzyme. Binary mixtures of chlorfluazuron with either teflubenzuron or pyriproxyfen produced a clear potentiation, especially in the resistant strains. On the other hand, there was no detectable joint action with fenvalerate, phenthoate, or thiodicarb. Potentiation of

chlorfluazuron by teflubenzuron and pyriproxyfen might be due to interference at the site of action and/ or with the chlorfluazuron degradation enzyme by teflubenzuron and pyriproxyfen (Fahmy and Miyata, 1998).

Practical usage problems with insecticide synergists

Despite the high potential benefits of synergists for insecticide resistance management, several major obstacles to their practical usage remain. Among these is the added cost to already expensive insecticides. Whether synergists can be discovered, developed, and produced as major cost-effective products remains to be seen. Most likely, cost effectiveness will vary from system to system, depending on the crop, insect species, and resistance level involved. Efficacy and insecticide use patterns will justify the additional investment in certain instances, but not in others. Registration also poses a formidable problem. Each component of a mixture, as well as the combination, must undergo full toxicological and environmental testing. This is a necessary but very expensive requirement. The problem is almost as complex for synergists of old registered products as for new insecticides. The synergist and the combination must each undergo full-scale testing, and in some assays the old insecticide must be again tested alone to give the baseline data for measuring nontarget synergism. In some instances, formulation can be a critical problem. This is particularly true where the insecticide and synergist have different polarities. Even if the materials can be placed in solution together, there is no guarantee that they will not separate during storage, during application, on or in the plant, or inside the insect. Adjuvants and surfactants are sometimes necessary to ensure good insecticide synergist mixtures. Also the formulation must be photostable and nonphytotoxic. Even if compatible formulations are available, simultaneous application may not be physiologically optimal. In some cases, the synergist is much more effective when it is applied several hours before the insecticide. From a research standpoint, this is the best way to study synergists because competitive uptake is eliminated. But can we really expect a grower to make two applications for one treatment? Again, the answer is "probably not." The rates that can be applied to yield synergism are also a limiting factor. In a matrix of synergist concentration *us* insecticide concentration (Fig. 1), we typically find two threshold values: a synergist dose, below which the insecticide cannot be synergized regardless of its concentration, and an insecticide dose, below which no amount of synergist is effective. Any commercially-applied mixture would have to fit within the highly active portion of this matrix.

The ratio of synergist to insecticide concentrations is another critical factor. It is not surprising that synergism increases with this parameter, but the slope of this relationship depends on the class of compounds involved. Certain compounds are extremely active at high synergist to insecticide concentration ratios, but then drop off very quickly. Other compounds show a more gradual slope. From a research standpoint, the synergists with the highest maximum activity are probably the most useful, regardless of their poor performance at the lower ratios. However, from a commercial standpoint, the most economically feasible mixtures are those to which the least amount of synergist need be added. The problems that we have mentioned for synergist commercialization are for the most part operational. We can always seek a material that is cheap, environmentally safe, compatible with the insecticide formulation, and effective at low rates. There is, however, a more basic problem: Because synergists attack specific metabolic pathways, they tend to have a relatively narrow spectrum of activity. This is, after all, what makes them such useful research tools. Unfortunately, this same trait is not desirable in the field.

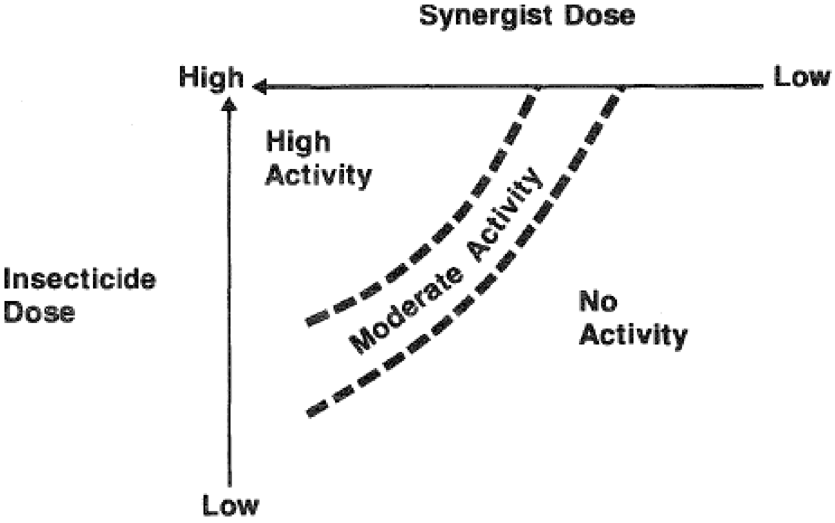

Fig. 1: Mortality levels resulting from different dosage levels and ratios of insecticide-synergist combinations. Only a narrow range of combinations gives adequate control, with thresholds occurring for both the insecticide and synergist

Future trends in synergist research and use

As we have seen, the transition from discovering a synergist in the laboratory to achieving field utility is a very difficult one. Perhaps one reason for this is that traditional approaches have emphasized the interactions among the insect, insecticide and synergist, but have ignored the host plant. Trying to incorporate the plant into the control strategy after the treatment has been devised is indeed a difficult task. Rather than being a hurdle to overcome, the intact plant-insect system may itself provide some research leads. We have provided some examples below of how the concept of synergism can be viewed in a broader sense. Schuster *et al.* (1983) found that fenvalerate is much more effective on cotton varieties with high tannin content than those with low tannin. In this case, the two materials are acting synergistically on tobacco budworms, which can normally tolerate high tannin levels. Likewise, high gossypol content increases the activity of monocrotophos and phosfolan on *Spodoptera littoralis* (Boisduval) (Meisner *et al.* 1977; Meisner *et al.* 1982). In another form of plant-mediated potentiation, Bigley *et al.* (1981) found that both toxaphene and cedar oil can increase the effectiveness of methyl parathion on cotton. These materials effectively compete for uptake on the leaves, thereby increasing the persistence of methyl parathion. An even more intriguing factor is that plant allelochemics can induce the insect's MFO and Glutathione-S-transferase systems (Yu 1983). This could explain why one insecticide is more effective on some crops than on others. One possibility is that this host-mediated induction of insecticide detoxification systems could be chemically inhibited. If so, combining such inhibitors with insecticides could increase efficacy among those strains which rely on induction for high detoxification capacity. In any event, we need to remind ourselves that our ultimate objective is to interfere with the natural plant-insect interaction, not kill insects in the laboratory. The crop species is the one common denominator to all of the pests a grower wishes to control. Finally, the use of synergists in neutralizing insect resistance mechanisms is not limited to classical insecticides. Again, synergism does not necessarily connote classical metabolic inhibition here, but includes greater-than-additive activity of any sort. For example, synergists have already been discovered for insect growth regulators (EI Guindy et a1. 1980; Granett and Hejazi 1983), insect viruses (Tanada and Hara 1975; Mohamed et a1. 1983), *Bacillus thuringiensis* (Habib and Garcia 1981), antifeedants (Moustafa et a1. 1980), and pheromones (Pitman et a1. 1975). Integration of synergists with novel control methods may assist these approaches in becoming effective enough to achieve field utility. If so, then a fundamental contribution of synergists to insecticide resistance management will again be an indirect one: Alternation and/or combinations of novel control methods with traditional insecticides could greatly decrease the development of resistance to either agent.

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DRONES: SUSTAINABLE TECHNOLOGY FOR FUTURE AGRICULTURE – A REVIEW

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Abstract:

This article's logical headings and subheadings offer a thorough grasp of agricultural drones. This paper provides an overview of drone technology as it relates to agricultural applications, such as farm operations and crop health monitoring. The usage of UAVs in agriculture also highlights anticipated future prospects for agricultural technology. The main idea revolves around the instance of the agricultural drone in order to identify a particular trend and inventive success. The technological features, benefits, and drawbacks of widely utilized agricultural drones are highlighted in this article. This will assist the reader in understanding the potential applications of drone use in agriculture in the future.

Keywords: Agriculture drones, Aircrafts, Multispectral Images, Anticipated Future, Unmanned Aerial Vehicle, Precision Farming, Crop Growth, and Mapping.

Introduction:

A drone used for agriculture is a "unmanned aerial vehicle" that is used to track the growth and productivity of crops. Farmers can see a more detailed picture of their fields with the use of sensors and digital photography capabilities. By using this information, agricultural productivity and crop yields may be increased. Drones used for agriculture enable farmers to view their farms from above. An aerial perspective can disclose various concerns, including but not limited to irregular soil, pest and fungus infestations, and issues with irrigation. Both a visual spectrum view and a near-infrared view are displayed in multispectral photographs. The combination helps the farmer distinguish between plants that are healthy and those that are unwell, even though these distinctions aren't always obvious to the unaided eye. Therefore, evaluating crop development and productivity can be aided by various perspectives. Fig 1 gives a clear view of Drones in Agriculture.

Fig. 1: Drones used for agriculture

Importance and studies related to drone

Large areas of land cleared by tractors and mechanized harvesters, combined with the use of genetically modified organisms (GMOs) to boost crop immunity, have virtually supplanted the practice of subsistence farming with bullocks. And the next stage of agricultural development is a large-scale single crop unit that would produce output never seen before due to the employment of drones for various purposes. Food security will become a pressing concern due to the world's population growth, environmental degradation, global warming, and shrinking arable land. To feed the world's burgeoning population, innovative farming techniques and widespread drone use will be needed. Given that there will be roughly 10 billion people on the planet by 2050, agricultural output will need to double in order to prevent a food shortfall. The global market for drone-powered commercial solutions was estimated to be worth $127.3 billion in 2016 by PricewaterhouseCoopers. The potential use of drones in international projects for agriculture was estimated to be worth $32.4 billion. According to the same study, the expected increase in population from 7 billion to 9 billion people by 2050 would result in a 69% increase in agricultural consumption between 2010 and 2050. According to the report, in order to meet demand, the agriculture sector may need to find strategies to enhance harvest output and food production techniques while maintaining sustainability and minimizing environmental harm. Drones are utilized in agriculture for planting, crop spraying, crop monitoring, irrigation, soil and field study, and health evaluation, according to an article published in the MIT Technology Review. The paper further clarified that, in comparison to their consumer-grade equivalents, agricultural drones are more sophisticated data collection instruments for serious specialists.

Uses of agricultural drones

- Surveys and data collection can be conducted using it. Thus, in order to facilitate real-time monitoring, a high-quality camera will be necessary.
- Thermal imaging-enabled drones can assist farmers in identifying well-watered areas of their farm.
- Imaging technologies and sensors can help prevent issues arising from soil erosion and damage.
- Can be used for aerial topdressing, which involves spreading fertiliser over the field specifically.
- Can be used for crop dusting, which involves spraying crops with crop protection products and planting of certain types of seed.
- Identifying the kinds of pests and the areas of the farm they are affecting can also be done effectively with an agricultural drone.

Applications of agricultural drones

- Mapping resources: Mapping crops and resources across a certain area is one of the main uses of drones in agriculture. Mapping crops at the field scale and evaluating their health might be crucial for making the right decisions. In order to determine crop health and yield potential, it is also helpful to examine the state and health of crops in various soil types and management zones. This helps to drive the growth of the agriculture drone market for field mapping applications.

- Reaching the unreached: Drones may gather data from locations that would be challenging to get manually, such steep terrain, areas flooded with water, etc. Additionally, it has shown to be very successful in gathering data from tall orchard crops across a wide area in a top-down manner for prompt monitoring and early infection diagnosis.
- Real-time imaging: The spatial and temporal dynamics of the agricultural system are excessively high. Because of this, monitoring for proper management necessitates having high temporal resolution capabilities in the relevant spatial area. Drones have the capability to obtain real-time ground truth at a spatial resolution of a few centimetres, something that is not achievable with satellite imaging or aircraft-based surveillance.
- Monitoring and specialised uses: When fitted with the appropriate sensors, drones can be utilised for a number of practical field applications due to their capacity to fly and record significant variations in field scale.
- Geo-fencing: Drones can also be utilised for security purposes as a virtual region or boundary around any geographical area. These days, wild creatures like elephants, nilgai, mountain bulls, wild boars, birds, etc., assault a lot of crops and cause damage. By sending the owner a text message anytime there is an intruder in a Geo-fenced area, geo-fencing can help deter these animals' attacks.
- Crop insurance: Aerial images obtained from drones can be utilised to rapidly categorise surveyed areas as cultivated or non-cultivated land and to determine the extent of damage caused by natural disasters. Aside from being easily replicable and quickly available, on demand area-specific drone imagery is also beneficial to crop insurers and insurance policy holders. Insurance companies in India intend to estimate crop losses during natural disasters using unmanned aerial vehicles (UAVs), which will enable them to compute payouts more rapidly and precisely. Farmers might receive data from insurance companies regarding the early identification and forecasting of pest infestations, which could be facilitated by drone data. Lastly, insurance fraud can be identified using drone data, which will stop fraudsters from insuring the identical item.

Drone applications for agriculture

1) Gamaya

The startup Gamaya, based in Switzerland, claims to have combined agricultural science, machine learning, and remote sensing technologies in its hyperspectral imaging camera, which is designed to be installed on drones. Light aircraft may also have the camera installed. Hyperspectral cameras, according to the company, measure the light reflected by plants. It states that it can record 40 colour bands in the visible and infrared spectrum—ten times more than existing cameras that can record a maximum of four colour bands. Additionally, the organisation clarifies that light is reflected variably by plants with varying physiologies and features. The pattern varies as the plant develops and experiences various stimuli. After comparing the collected photos with those in its database, the camera's application applies machine learning to transform the imaging data into information. It then assigns particular circumstances with a color.

2) Iris Automation

The Iris Collision Avoidance Technology for Commercial Drones is an application created by Iris Automation that enables drones to see and understand their environment and moving aircraft in order to prevent collisions. According to the company, this application can be used in package transportation, mining, oil and gas, and agriculture. With regard to agriculture specifically, the business states that the drone application can let farmers safely engage with other drones while scanning crops, planting seeds, and managing pests.

3) Sense fly

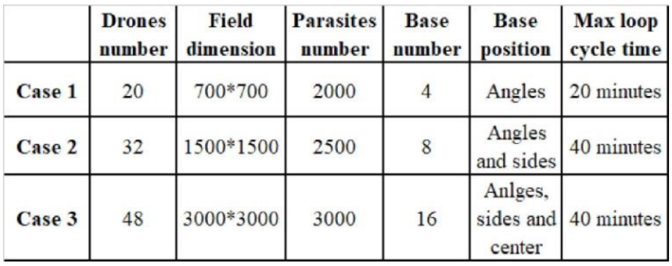
Sense Fly provides the Ag 360 computer vision drone, which enables farmers to monitor crops at various growth stages and evaluate soil conditions by taking infrared pictures of fields. This might help farmers monitor the health of their plants and calculate how much fertilizer is needed to prevent waste. The emotion software functions in tandem with the drone.

UAS for smart farming

UAS that are used in precision farming function at various elevations. Drone operators can act like a sprayer at a very modest elevation over a field, or they can capture high quality images from a hundred meters height for autonomous analysis of individual leaves on a maize plant. By definition, an Unmanned Aerial Vehicle (UAV) is a drone, a data link system (DLS), and a ground control station (GCS) make up a UAS. Using machine learning and predictive modeling, it would assist farmers in keeping an eye on field conditions and in acquiring, gathering, and processing intelligent pixels and signals from the ground into multimodal knowledge. Over time, it would facilitate more efficient operations and result in food of higher quality using less water.

Performance evaluation

This part displays the performance evaluation in terms of the number of recharge bases, position, and time at which parasites are eliminated. Along with a set of fixed parameters, the simulator also offers a set of variable parameters. It displays a Graphical User Interface (GUI) where users can alter the values of parameters to mimic various scenarios.



	Drones number	Field dimension	Parasites number	Base number	Base position	Max loop cycle time
Case 1	20	700*700	2000	4	Angles	20 minutes
Case 2	32	1500*1500	2500	8	Angles and sides	40 minutes
Case 3	48	3000*3000	3000	16	Anlges, sides and center	40 minutes

Fig 2. Considered three cases

In particular, it will be shown the comparison between the random and the distributed search algorithm. The two algorithms are compared in three different cases as shown in the Fig. 1.

Pros of using drones

1) **Analysis**

Analysis of the soil and fields could be done with drones. With the use of these, precise 3-D maps that may be utilised for soil analysis on soil properties, moisture content, and soil erosion can be produced.

2) **Planting**

Some manufacturers have developed devices that can shoot pods holding seeds and plant nutrients into the soil that has already been prepared, albeit they are not quite common yet. This significantly lowers the cost of planting.

3) **Monitoring**

A major challenge in farming is the ineffective crop monitoring of wide areas. The emergence of erratic weather patterns, which raise risks and maintenance expenses, exacerbates this problem. Utilising drones, time series animations may be created to demonstrate accurate crop development and highlight production inefficiencies, leading to improved crop management.

4) **Drones for Agriculture Spraying**

When topography and geography change, drones may adapt their height using ultrasonic echoes and lasers. They can accurately and instantly spray the right amount of the needed liquid because of their ability to scan and adjust their distance from the ground. This minimises the amount of water that seeps into groundwater, increasing efficiency. Drone spraying has also shown to be faster than other conventional techniques.

5) **Irrigation**

Drones having thermal, hyper-spectral, or thermal sensors are able to detect areas of the field that have dried up. In this manner, irrigation may be timely and precisely applied to the regions that have been identified.

6) **Health Assessment**

Certain drones can use visible and near-infrared light to scan crops. The amount of green and near-infrared light reflected by the plants is then detected by on-board light processing equipment. The health of the plant is then depicted in multi-spectral images created using this data. These photos can be used to monitor crop health and, in the event that a disease is found, to trace the treatment that is given.

7) **Ease of Deployment**

Unlike traditional aircraft, the drones are easier and cheaper to deploy.

Cons of agricultural drones

1) Duration of flight and altitude

The majority of drones can only fly for 20 to 60 minutes at a time. This restricts the amount of land it can cover with each charge. The radius that can be covered throughout each flying time is likewise restricted by the flight range. Longer flying times and greater range are available in more expensive drone models.

2) Original purchase price

The attributes that make drones suitable for use in agriculture come at a high cost. This is mostly true for drones with fixed wings, which can cost up to $25,000. Drone use for agricultural purposes is classified as commercial. This implies that in order to obtain a remote pilot certificate, the farmer must either employ an operator who meets the requirements or complete FAA operator training. The FAA further mandates that drone only be flown 400 feet or less in the air.

3) Interference in the airspace

Drones used for agriculture and manually operated aircraft fly in the same airspace. They are therefore vulnerable to interference.

4) Interconnectivity

There is extremely little, if any, internet coverage of the majority of US agricultural farmlands. This means that every farmer who wants to use drones will need to either purchase a drone that can capture and store data locally in a manner that can be processed later, or invest in connection.

5)Weather-related

Compared to traditional aircraft, drones are far more susceptible to weather conditions. It might not be possible for you to fly them if it is extremely windy or rainy outside.

6) Expertise and ability

For the photos to yield any meaningful information, they must be analysed by a qualified and experienced team. This implies that a typical farmer lacking these abilities could require instruction or might have to employ a knowledgeable employee familiar with the analytic software to assist with the image processing.

Future scope:

Future agricultural drones will help farmers cut back on their excessive water use, and by spraying plants that need attention, they will also help lessen the amount of chemicals that are released into the environment. As a result, this may be referred to as a green technology tool in the future. Drones can be effectively employed in a variety of businesses, including the military and pizza delivery, and are not just limited to the agricultural sector. The governments of industrialized nations are concentrating on outlining a beneficial plan to boost the use of these drones by raising financing and bringing agricultural innovations to market.

Conclusion:

Agricultural drones have the ability to improve crops and provide information into disease management techniques using imagery and sensors. Because it can estimate when water will flow through glaciers, it will also be useful in monitoring irrigation and water supplies. Farmers can revolutionise the agriculture sector with the use of agricultural drones. In conclusion, the use of drone technology in the agricultural industry has the potential to revolutionize crop management practices and increase yields.

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UNLEASHING ANTISENSE TECHNOLOGY IN SEED QUALITY IMPROVEMENT

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Abstract:

Antisense technology represents a transformative approach in agricultural biotechnology, offering significant advancements in seed quality improvement. This technology involves the synthesis of antisense RNA molecules that are complementary to specific mRNA sequences within the target plant. By binding to these mRNAs, antisense RNA effectively blocks their translation, thus downregulating or silencing the expression of undesirable genes. This precise gene regulation method has profound implications for enhancing seed quality traits, such as increased nutritional value, improved resistance to pests and diseases, and extended shelf life. One of the primary applications of antisense technology in seed quality improvement is the reduction of anti-nutritional factors and allergens, making seeds more suitable for consumption and processing. For instance, the suppression of genes encoding for protease inhibitors or phytic acid can lead to seeds with enhanced digestibility and bioavailability of essential nutrients. Additionally, antisense-mediated downregulation of ethylene production can delay seed senescence and spoilage, thereby extending storage life and reducing post-harvest losses. Furthermore, antisense technology can be utilized to enhance stress tolerance in seeds. By targeting and silencing genes involved in stress responses, plants can be engineered to withstand adverse environmental conditions, such as drought, salinity, and extreme temperatures, thereby ensuring stable crop yields. The precision and specificity of antisense RNA make it a powerful tool for trait improvement without the introduction of foreign DNA, addressing public concerns about genetically modified organisms (GMOs).

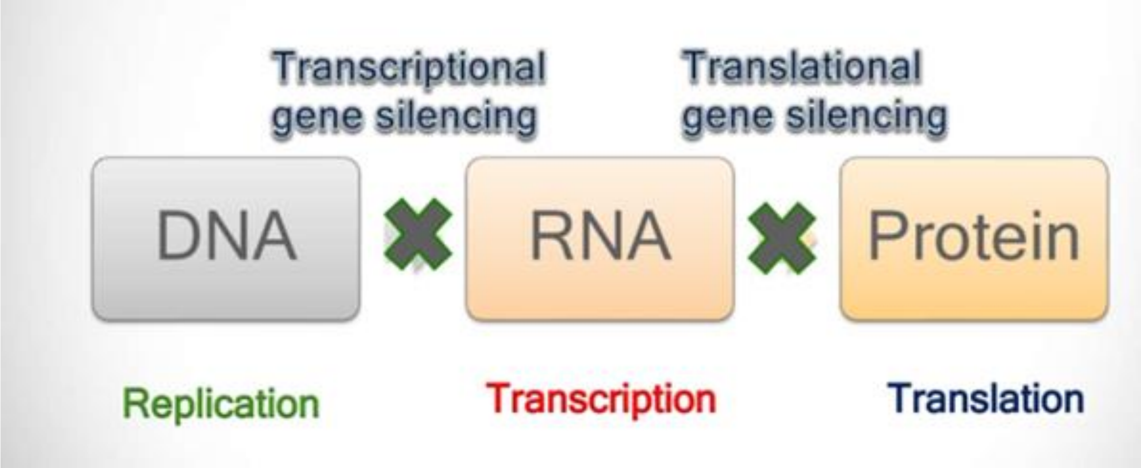
Introduction:

The world population has reached around 7.7 billion and it is projected to reach 9.7 billion by 2050 (Rajam, 2020). To satisfy the world food demand, improving the production and productivity of food crops is required. Since domestication, people have been selecting the best germplasm over the other to improve productivity, environmental adaptation, and quality. The foremost important crops that we cultivate and consume nowadays are the invention of centuries, before Mendel's work of genetics of plant breeding. The current long- standing dream of crop improvement often combines traditional plant breeding with the inventions made possible by biotechnology. This effort has begun with conventional methods, the subliminal selection by early agricultural societies of genotypes with high yields and good agronomic properties, followed by molecular methods, and thus the growth of scientific plant breeding over the past century. On the other side, climate change and environmental stresses have major implications on worldwide crop production which calls for the development of crops that can resist a range of climate changes and environmental stresses such as irregular water-supplies leading to drought or water-logging, hyper soil-salinity, extreme and variable temperatures, ultraviolet radiations, and metal stress.

The molecular methods of crop improvement currently under use include hybridization, mutation, tissue culture, and antisense technology (Kim *et al.*, 2014). Antisense technology is the most convenient and novel technology employed by crop breeders for the development of various crop species/varieties. Antisense technology is a comprehensive term, which includes antisense RNA (asRNA), RNA interference (RNAi), long non-coding RNA (lncRNA), and several other enzymes and molecules. The types and mechanisms of antisense technology have discussed here.

Antisense technology

Antisense technology is a tool that is used for the Inhibition of gene expression. The principle behind it is that an antisense nucleic acid sequence base pairs with its complementary sense RNA strand and prevents it from being translated into a protein. The complimentary nucleic acid sequence can be either a synthetic oligonucleotide, often oligo deoxyribo nucleotides (ODN) of less than 30 nucleotides, or longer antisense RNA (asRNA) sequences. An example of sense and antisense RNA is: - 5’ACGU3’ mRNA, and 3’UGCA5’ Antisense RNA.



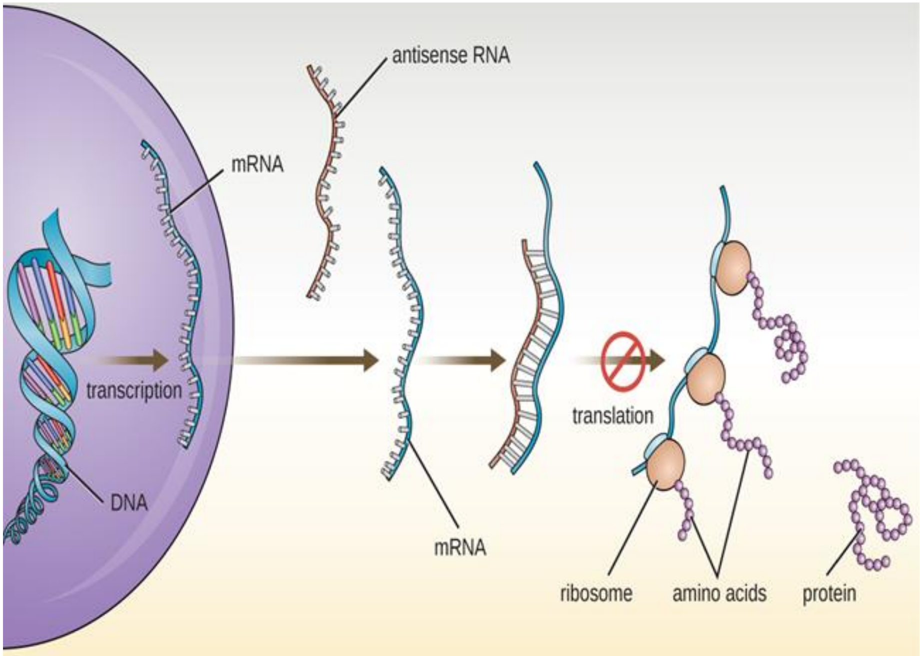
Central dogma of life

In Antisense technology, synthetically – produced complementary molecules seek out and bind to messenger RNA (mRNA), blocking the final step of protein production. mRNA is the nucleic acid molecule that carries genetic information from the DNA to the other cellular machinery involved in the protein production. By Binding to mRNA, the antisense drugs interrupt and inhibit the production of specific disease related proteins1.

"Sense" refers to the original sequence of the DNA or RNA molecule. "Antisense" refers to the complementary sequence of the DNA or RNA molecules1.

The basic idea is that if an oligonucleotide (a short) RNA or DNA molecule complementary to a mRNA produced by a gene) can be introduced into a cell, it will specifically bind to its target mRNA through the exquisite specificity of complementary based pairing the same mechanism which guarantees the fidelity of DNA replication and of RNA transcription from the gene. This binding forms an RNA dimmer in the cytoplasm and halts protein synthesis. This occurs because the mRNA no longer has access to the ribosome and cytoplasm by ribo nucleotide H. Therefore, the introduction of short chains of DNA complementary to m RNA will lead to a specific diminution, or blockage, of protein synthesis by a particular gave.

General outline antisense mechanism



Antisense technology is the process in which the antisense strand hydrogen bonds with the targeted sense strand. When an antisense strand binds to a mRNA sense strand, a cell will recognize the double helix as foreign to the cell and proceed to degrade the faculty mRNA molecule thus preventing the production of undesired protein. Although DNA is already a double stranded molecule, antisense technology can be applied to it building a triplex formation. A DNA antisense molecule must be approximately seventeen bags in order to unction, and approximately thirteen bases for an RNA molecule RNA antisense strand can be either catalytic, or non-catalytic. The catalytic antisense strands, also called ribozymes, which will cleave the RNA molecule at specific sequences. A Non catalytic RNA antisense strand blocks further RNA processing, i.e. modifying the mRNA strand or transcription.

History

Antisense technology was first developed by Dr. Hal Weintraub at Basic Science Division. Firstly, they showed that asRNA inhibits the gene expression in mouse cells in early 1980s. The idea of asRNAs as drug targets started in 1982 when Zamecnik and Stephenson found an antisense oligonucleotide to the viral RNA of Rous scarcoma virus that was capable of inhibiting viral replication and protein synthesis.

Theories on how Inhibition works

When the aRNA binds to the complementary mRNA. It forms a double stranded RNA (ds-RNA) complex that is similar to double-stranded DNA. The ds-RNA complex does not allow normal translation to occur. The exact mechanism by which translation is blocked is unknown. Several theories include:

- That the ds-RNA prevents ribosomes from binding to the sense RNA and translating.
- The ds-RNA cannot be transported from within the nucleus to the cytosol. This is where translation
- 2occurs.
- That ds-RNA is susceptible to endo ribonucleases that would otherwise not affect single stranded
- RNA but degrade the ds-RNA.

Types of Antisense Strategies

Based on strategy on how protein synthesis is blocked, Antisense technology of 3 types

1. By antisense oligonucleotides
2. By ribosomes
3. RNA interference

1. Antisense-Oligonucleotides

Antisense oligonucleotides (AS ONs) are synthetic DNA oligomers that hybridize to a target RNA in a sequence-specific manner. Zamecnik and Stephenson first demonstrated the antisense effect of synthetic nucleotide. Generally, it consists of 15–20 nucleotides. These oligonucleotides are complementary to their target mRNA, which physically bind to the mRNA. So, they block the expression of particular gene (Zhou *et al)*. The antisense oligonucleotides can affect gene expression in two ways: by using an RNase H-dependent mechanism or by using a steric blocking mechanism.

Mechanism of AS-ON: On the basis of mechanism of action two classes of antisense oligonucleotide can be there

i. RNase H-dependent oligonucleotide: which induce degradation of mRNA.
ii. Steric blocker oligonucleotides: which physically block protein synthesis.

Mechanism of Antisense-Oligonucleotide

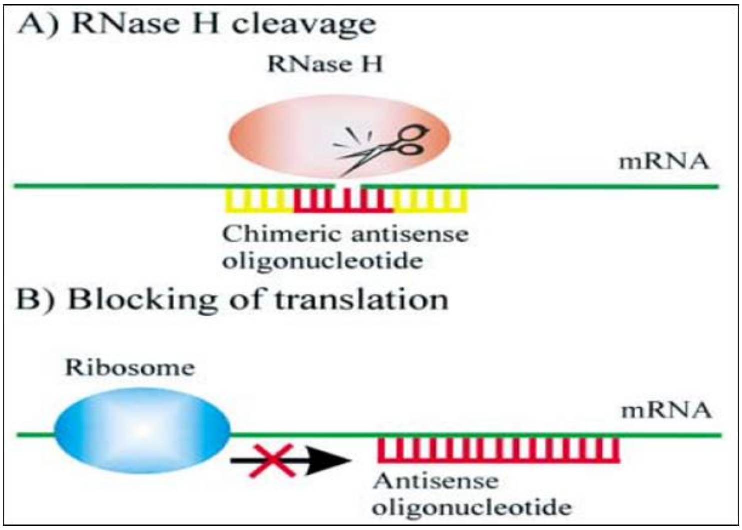
(a) Endocytosis: One of the simplest methods to get nucleotide in the cell, it relies on the cells natural process of receptor mediated endocytosis. The drawbacks to this method are the long amount of time for any accumulation to occur, the unreliable result, and the inefficiency.

(b) Micro-Infection: As the name implies, the antisense molecule would be injected into the cell. The yield of this method is very high, but because of the precision needed to inject a very small cell with smaller molecules only about 100 cells can be injected per day.

(c) Liposome–Encapsulation: This is the most effective method, but also a very expensive one. Liposome encapsulation can be achieved by using products such as lipofect ACE™ to create a cationic phospholipids bilayer that will surround the nucleotide sequence. The resulting liposome can merge with the cell membrane allowing the antisense to enter the cell.

(d) Electroporation: The conventional method of adding a nucleotide sequence to a cell can also be used. The antisense molecule should transverse the cell membrane offer a shock is applied to the cells.

(e) Antisense PG gene: The PG enzyme is responsible for the breakdown pectin. Pectin is a building block in cell walls, and is what gives tomatoes their firmness. In an attempt to slow the softening process, the Flavr Savr employs antisense technology to block PG enzyme production. The use of antisense PG RNA is because the mRNA it generates is complementary to the mRNA produced by regular PG genes, it will actively inhibit PG enzymes by disabling their mRNA. This disabling is accomplished by having the small antisense fragment mRNA bind to the regular PG mRNA. This partial double-stranded complex will not for PG protein, and the complex is quickly degraded.



Inserting Antisense into cells

Modifications of AS-ON:

Once we introduce synthetic oligonucleotide into cell it acts as invade or foreign material to cell and thus can become prey for endonuclease enzyme, so in order to protect oligonucleotide from endogenous nucleotide protective modification could be introduced to nucleotide

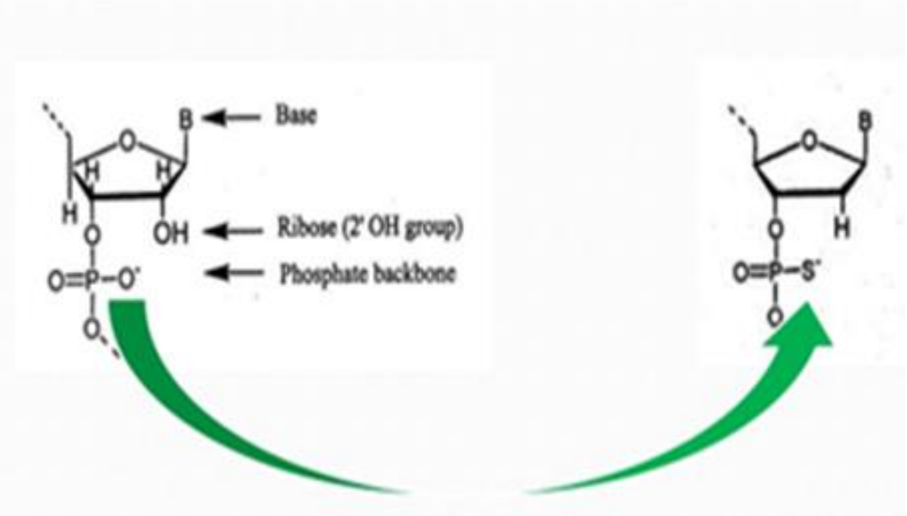
Based on modification AS-ON are of 3 types:

i. First generation AS-ON
ii. Second generation AS-ON
iii. Third generation AS-ON

First generation antisense-oligonucleotides:

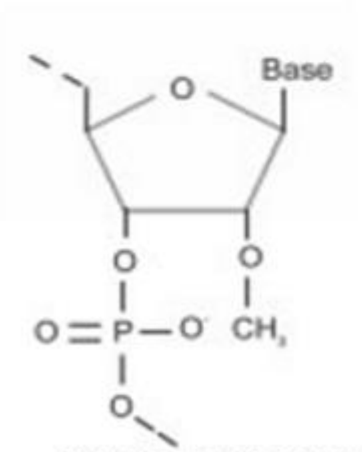
The first generation of antisense agents contains backbone modifications such as replacement of oxygen atom of the phosphate linkage by sulphur (phosphorothioates), methyl group (methyl phosphonates) or amines (phosphoramidates) Of these, the phosphorothioates have been the most successful and used for gene silencing because of their sufficient resistance to nucleases and ability to induce RNase H functions. Phosphorohioate oligonucleotides were first synthesized in the 1960s by Eckstein and colleagues and were first used as Antisense-oligonucleotides (ASONs) for the inhibition of HIV replication by Matsukura and co-workers. However, their profiles of binding affinity to the target sequences, specificity and cellular uptake are less satisfactory (Guanghui *et a)l*.

Here one of the non-bridging oxygen atoms in the phosphate backbone with a sulfur atom. This modification was called as phosphorothioate that achieved the goal of nuclease resistance.

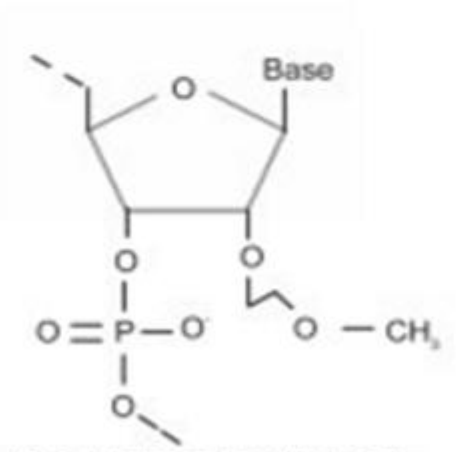


Second generation antisense-oligonucleotides:

The problems associated with phosphorothioate oligo deoxynucleotides are to some degree solved in second generation oligonucleotides containing nucleotides with alkyl modifications at the 2' position of the ribose. 2'-O-methyl and 2'-O-methoxyethyl RNA are the most important members of this class. 2'-O-methyl and 2'-O-methoxyethyl derivatives can be further combined with phosphorothioate linkage. Antisense oligonucleotides made of these building blocks are less toxic than phosphorothioate ASONs and have a slightly enhanced affinity towards their complementary RNAs. Questions regarding its efficiency to induce RNase H cleavage of the target RNA are the matter to concern regarding this second-generation oligonucleotide (Shi *et al)*. Since RNase H cleavage is the most desirable mechanism for antisense effect and since 2-O-alkyl modifications are desirable for nuclease resistance, a hybrid oligonucleotide construct incorporating both characteristics has appeared in the form of the “gapmer” antisense oligonucleotide. A gapmer contains a central block of deoxynucleotides sufficient to induce Rnase H cleavage flanked by blocks of 2'-O-methyl modified ribonucleotides that protect the internal block from nuclease degradation.



2'-O-Methyl (2'-OME)



2'-O-Methoxyethyl (2'-MOE)

Third generation antisense-oligonucleotides:

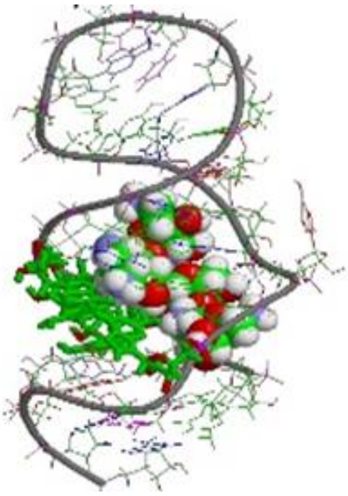
A variety of nucleic acid analogs have been developed that display increased thermal stabilities when hybridized to with complementary DNAs or RNAs as compared to unmodified DNA:DNA and DNA:RNA duplexes. These are the third-generation antisense oligonucleotide modifications. The third generation contains structural elements, such as zwitter ionic oligonucleotides (possessing both positive and negative charges in the molecule); Peptide Nucleic Acids (PNAs) (with a pseudo peptide backbone), Locked Nucleic Acids (LNAs)/Bridged Nucleic Acids (BNAs), Hexitol Nucleic Acids (HNA) and Morpholino oligonucleotides. PNAs are dramatic alterations in which the sugar phosphate backbone is replaced completely by polyamide linkages. While these constructs afford increased stability and favourable hybridization kinetics, they suffer from being unavailable to the RNase H cleavage mechanism, problematic solubilities and delivery difficulties. The newest and most promising third generation modification is the Locked Nucleic Acids (LNAs). LNAs nucleotides are a class of nucleic acid analogues in which the ribose ring is “locked” by a methylene bridge connecting the 2'-O atom and the 4'-C atom. LNAs were immediately seen to display remarkably increased thermodynamic stability and enhanced nucleic acid recognition (Huibin *et al.*). LNAs has been proven to be a powerful tool in many molecular biological applications in which standard DNA oligonucleotides or RNA riboprobes do not show sufficient affinity or specificity.

1. Ribozyme

- Ribozyme are RNA molecule or catalytic enzyme that catalyses biochemical reactions.
- 1982: Ribozyme were first discovered by Thomas Czech and Sidney Altman.
- 1982: The term ribozyme was introduced by Kelly.
- 1989: T. Czech and S. Altman shared Noble Price in chemistry for discovery of RNA that act as an enzyme

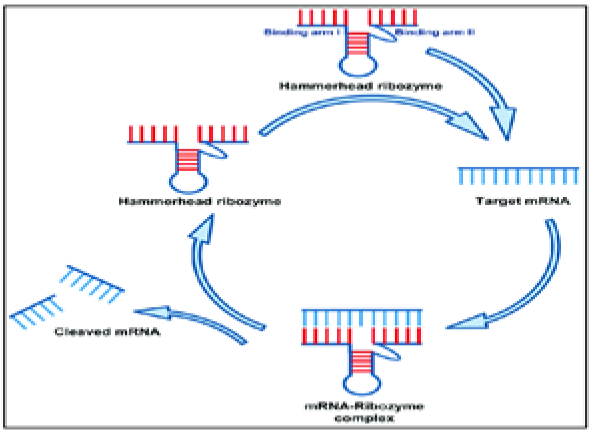
S. Altman

T. Cech



3D Ribozyme Molecule

2. Mechanism of ribozymes



The nucleolytic ribozymes bring about the site-specific cleavage of RNA by attack of a 2′-hydroxyl group on the adjacent 3′-phosphorus (or by the 5′-hydroxyl group in the reverse reaction). This is used in the processing of replication intermediates, and in the control of gene expression. Ribonuclease P carries out the processing of tRNA in all domains of life, using a hydrolytic reaction. A number of introns are spliced out auto catalytically by ribozyme action, initiated either by the attack of a 2′-hydroxyl group located remotely within the intron (group II introns), or by an exogenous guanosine molecule (group I introns). The similarity of the chemistry of mRNA splicing in the spliceosome to that of the group II introns makes it very likely that this too is at least partially RNA catalysed, where snU4/U6 RNA is the ribozyme. Finally, the peptidyl transferase activity of the ribosome catalyses the condensation of amino acids into polypeptides, which is one of the most important reactions of the cell.

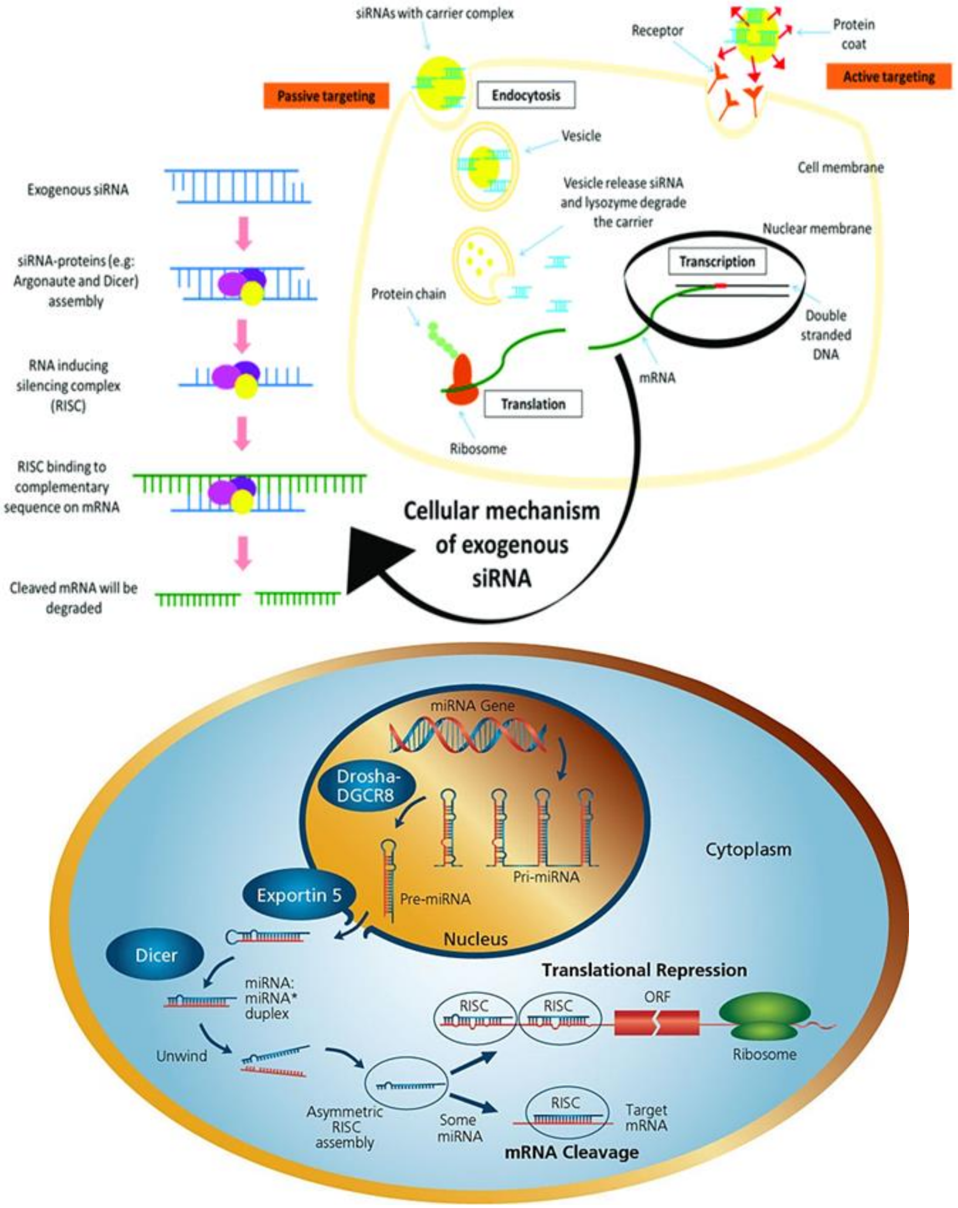
3. RNA interference

RNA interference (RNAi) is a biological process in which RNA molecules are involved in sequence-specific suppression of gene expression by double-stranded RNA, through translational or transcriptional repression. Historically, RNAi was known by other names, including co-suppression, post-transcriptional gene silencing (PTGS), and quelling. The detailed study of each of these seemingly different processes elucidated that the identity of these phenomena was all actually RNAi. Andrew Fire and Craig C. Mello shared the 2006 Nobel Prize in Physiology or Medicine for their work on RNA interference in the nematode worm caenorhabditis elegans, which they published in 1998. Since the discovery of RNAi and its regulatory potentials, it has become evident that RNAi has immense potential in suppression of desired genes. RNAi is now known as precise, efficient, stable and better than antisense therapy for gene suppression. Antisense RNA produced intracellularly by an expression vector may be developed and find utility as novel therapeutic agents.

Two types of small ribonucleic acid (RNA) molecules – micro RNA (miRNA) and small interfering RNA (siRNA) – are central to RNA interference. RNAs are the direct products of genes, and these small RNAs can direct enzyme complexes to degrade messenger RNA (mRNA) molecules and thus decrease their activity by preventing translation, via post-transcriptional gene silencing. Moreover, transcription can be inhibited via the pre-transcriptional silencing mechanism of RNA interference, through which an enzyme complex catalyses DNA methylation at genomic positions complementary to complexed siRNA or miRNA. RNA interference has an important role in defending cells against parasitic nucleotide sequences – viruses and transposons. It also influences development.

The RNAi pathway is found in many eukaryotes, including animals, and is initiated by the enzyme Dicer, which cleaves long double-stranded RNA (dsRNA) molecules into short double-stranded fragments of ~21 nucleotide siRNAs. Each siRNA is unwound into two single-stranded RNAs (ssRNAs), the passenger strand and the guide strand. The passenger strand is degraded and the guide strand is incorporated into the RNA-induced silencing complex (RISC). The most well-studied outcome is post-transcriptional gene silencing, which occurs when the guide strand pairs with a complementary sequence in a messenger RNA molecule and induces cleavage by Argonaute 2 (Ago2), the catalytic component of the RISC. In some organisms, this process spreads systemically, despite the initially limited molar concentrations of siRNA.

MicroRNA: These are genomically encoded non-coding RNAs that help regulate gene expression, particularly during development.[18] The phenomenon of RNA interference, broadly defined, includes the endogenously induced gene silencing effects of miRNAs as well as silencing triggered by foreign dsRNA. Mature miRNAs are structurally similar to siRNAs produced from exogenous dsRNA, but before reaching maturity, miRNAs must first undergo extensive post-transcriptional modification. A miRNA is expressed from a much longer RNA-coding gene as a primary transcript known as a pri-miRNA which is processed, in the cell nucleus, to a 70-nucleotide stem-loop structure called a pre-miRNA by the microprocessor complex. This complex consists of an RNase III enzyme called Drosha and a dsRNA-binding protein DGCR8. The dsRNA portion of this pre-miRNA is bound and cleaved by Dicer to produce the mature miRNA molecule that can be integrated into the RISC complex; thus, miRNA and siRNA share the same downstream cellular machinery.



Schematic diagram of the mechanism of siRNA and miRNA of gene silencing

Flavr savr tomato

Fruit ripening process

Fruit ripening is an active process characterized by increased respiration accompanied b a rapid increase in ethylene synthesis. as the chlorophyll gets degraded, the green color of fruit disappears and a red pigment, lycopene is synthesized. the fruit gets softened as a result of the activity of cell wall degrading enzymes namely polygalacturonase (PG) and methyl esterase. The phyto hormone ethylene production is linked to fruit ripening as the same is known to trigger the ripening effect. The breakdown of starch to sugars and accumulation of large number of secondary products improves the flavor, taste and smell of the fruits.

Genes involved

pTOM5 encodes for phytoene synthase which promote lycopene synthesis that gives red coloration. ptom6 gene encodes for polygalacturonase. this enzyme degrades the cell wall, resulting in fruit softening. pTOM gene encodes for ACC oxidase. This enzyme catalyzes the ethylene formation that triggers the fruit ripening.

Genetically modified tomato

A genetically modified tomato, or transgenic tomato is a tomato that has had its genes modified, using genetic engineering. The first commercially available genetically modified food was a tomato engineered to have a longer shelf life (FLAVR SAVR). First genetically engineered crop granted license for human consumption. Produced by Californian company Calgene 1992. Calgene introduced a GENE in plant which synthesize a complementary mRNA to PG gene and inhibiting the synthesis of PG enzyme. On May 21, 1994, the genetically engineered Flavr Savr tomato was introduced.

Development of flavr savr tomato

Softening of fruits is largely due to degradation of cell wall (pectin) by enzyme polygalacturonase (PG). The gene encoding PG has been isolated and cloned (pTOM6).

1. Isolation of DNA from tomato plant that encodes the enzyme polygalacturonase (PG).
2. Transfer of PG gene to a vector bacteria and production of complementary DNA (cDNA) molecules.
3. Introduction of cDNA into a fresh tomato plant to produce transgenic plant.

Mechanism of PGantisense RNA approach

In normal plants, PG gene encodes a normal or sense mRNA that produce the enzyme PG and it is actively involved in fruit ripening. The cDNA of PG encodes for antisense mRNA, which is complementary to sense mRNA. The hybridization between sense and antisense mRNA render the sense mRNA ineffective. Consequently, no polygalacturonase is produced hence fruit ripening is delayed.

Advantages of asRNA

- Antisense RNA technology specifically targets a gene in specic manner.
- This technique is a unique way to treat variety of diseases.
- The timing and extent of the gene silencing can be controlled.
- Inhibition of mRNA expression will produce quicker and longer lasting clinical response than inhibition of protein.
- Great degree of flexibility in the field of functional genomics.
- This is used to protect the genome from viruses.

Limitations of asRNA

- For the use of asRNA the exact sequence of the target gene is required, it difficult to obtain.
- In this technique there are off-target effects.
- Chance of degradation before stopping any protein production may lead to loss of technique.
- The delivery of finest and sufficient small RNAs in the targeted cells is difficult.
- It does not knockout a gene for 100% for practical.
- Antisense RNA technique is quite expensive for use.
- There are chance of ethical Problems.

The major applications and achievements of the antisense technology in crop improvement

Improved Traits	RNA Tools	Targeted Gene	Crops
Removing toxic compounds			
Removing linamarin	RNAi	CYP79D1/D2	Cassava
Removing ODAP	asRNA	CoA synthase	Khesari
Decaffeinating	RNAi	CaMXMT1	Coffee
Enhance nutrition value			
Lysine	RNAi	22-KD	Maize
Amylose	asRNA	Sbe2a	Wheat
Reduce glutinin	RNAi	Gliadins	Wheat
Reduced cadmium	RNAi	OsPCS1	Rice
Reduced erucic acid	RNAi	BnFAE1	Brassica
Fruit improvement			
Beta-carotenoids	RNAi	BCH	Potato
Carotenoids and flavonoids	RNAi	DEF1	Tomatoes
Seedless fruit improvement	RNAi	CHS	Tomato
Enhanced shelf life	RNAi	MaMADS1/S2	Banana
Reduce ethylene	RNAi	ACC synthase	Tomato
Biotic stress resistance			
Bacteria resistance			
Leaf blight	RNAi	OsSSI2	Rice
Fungal resistance			
Sheath blight pathogen	RNAi	RPMK1-1/-2	Rice
Apple scab fungus	RNAi	GFP & THN	Apple
Virus resistance			
Tobacco mosaic virus	asRNA	CP	Tobacco
PMMoV	RNAi	PMMoV replicase	Pepper
Insect resistance			
Helicoverpa armigera	RNAi	CYP6AE14	Cotton
Nematode	RNAi	Mi-msp2	Arabidopsis
Whitefly	RNAi	v-ATPase	Lettuce
Abiotic stress tolerance			
Salt tolerance	RNAi	TaPUB1	Wheat

Conclusion:

The antisense technology is one of the novel approaches that is gaining more acceptance in agricultural science for crop improvement both in quality and quantity. This technology is one of the most approved tools for inactivating a single specific gene and expected to be widely used for studies of genes with unknown function. Also, by using comparatively small transgene antisense technology permits silencing of targeted multiple genes in a single construct. Major improvements have been achieved by the development of modified nucleotides that provide high target affinity, enhanced bio stability and low toxicity. The RNAi-based antisense technology was found to be frequently applied (93%) especially on vegetables (41%), cereals (33%), cash crops (26%) to improve biotic resistance (29.6%) and also to enhance nutritional values (18.5%).It is even better than conventional transgenic technology where they generally need the expression of whole genes, whereas asRNA require comparatively small transgene for silencing, permitting multiple genes to be targeted in a single construct.

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EFFECT OF ZINC AND ALUMINIUM ON GROWTH AND DEVELOPMENT OF *VIGNA RADIATA*

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Abstract:

Metal contamination in the environment caused by industrial and human processes is a global issue. In this paper, information is provided on the effect of Zinc and Aluminium treatment on Mung bean seed germination as compared with the control one. Zinc sulphate and Aluminium sulphate are treated on *Vigna radiata* at different concentrations (50mg, 100mg, 150mg, 200mg) and had different effects on the growth parameters of shoot, root, seedling length and biochemical parameters of chlorophyll content and carbohydrate content. This paper mentioned hypocotyls and epicotyls length and estimated the presence of chlorophyll and carbohydrates by graphical representation.

Keywords: Heavy Metal, Stress Physiology, *Vigna radiata*, Chlorophyll, Carbohydrate.

Introduction:

The onset of industrialization has significantly increased the concentration of heavy metals in the environment, posing serious threats to soil resources, water, and human health (Ali *et al.*, 2019; Alloway, 2013). Heavy metals and metalloids, such as Hg, As, Pb, Cd, and Zn, disrupt human metabolism and adversely affect crop quality, leading to increased morbidity and mortality rates (Ashraf *et al.*, 2011; Chibuike & Obiora, 2014). In Kalahandi, an agricultural region where crops like pulses, millets, maize, and wheat are cultivated, heavy metal contamination from industrial activities, such as those from Vedant Ltd. Alumina Refinery in Lanjigarh, poses significant risks to crop plants (Ghani, 2011; Ghosh & Singh, 2005).

Mung bean (*Vigna radiata*): Origin and geographic distribution

Vigna radiata, commonly known as mung bean, is a legume plant of the Fabaceae family, widely cultivated for its edible seeds and sprouts (Gupta *et al.*, 2013). It is likely native to the Indian subcontinent and is widely grown across Asia, especially in India, China, Korea, and Thailand (Hassan *et al.*, 2019). Its cultivation has also spread to Africa, Australia, America, and the West Indies (Khan *et al.*, 2018).

Characteristics of the plant

Mung bean is an annual, terrestrial creeper that grows up to 0.5-1.3 meters tall. It has a well-developed tap root system with many slender lateral roots and root nodules (Khan *et al.*, 2000). The stem is much-branched, with young stems being purple or green and mature stems greyish-yellow or brown. Leaves are alternate, trifoliate, and dark green. The inflorescence is a false raceme that produces bisexual flowers, and the fruit is an elongated pod containing seeds that turn black or brown upon maturity (Nagajyoti *et al.*, 2010).

Growth and development of mung bean

Mung bean grows rapidly under warm conditions, maturing quickly in tropical and subtropical climates with optimal temperatures around 28-30°C and minimum germination temperatures of about 12°C. It is drought-tolerant but sensitive to waterlogging, preferring well-drained loams or sandy loams with pH levels between 5 and 8 (Parihar *et al.*, 2015). It flowers within 30-70 days and matures within 90-120 days after sowing (Pourrut *et al.*, 2011).

Nutritive value of green gram

Mature mung bean seeds are rich in nutrients, containing 23.9g of protein, 62.6g of carbohydrates, 16.3g of dietary fiber, and various vitamins and minerals per 100 grams. Essential amino acids include tryptophan, valine, leucine, and lysine (Sharma & Dubey, 2005).

World production and international trade

India and Myanmar are the largest producers of mung beans, contributing significantly to global production. In 2022-2023, India produced over 3 million metric tonnes, with major contributions from Rajasthan and Madhya Pradesh. Major buyers of Indian mung beans include the USA, UK, and China (Singh *et al.*, 2016).

Effects of heavy metal toxicity on *Vigna radiata*

Heavy metals affect all stages of plant life, causing issues such as chlorosis, reduced biomass, and growth inhibition (Ali *et al.*, 2019). Zinc and aluminum have distinct effects on *Vigna radiata*, with zinc deficiency causing short internodes and decreased leaf size, while high zinc and aluminum concentrations inhibit root and overall plant growth (Alloway, 2013).

Toxic effects of different heavy metals on *Vigna radiata*:

Heavy metal toxicity is a significant abiotic stress that adversely affects plant growth and development. Both essential metals (Fe, Co, Zn) and non-essential metals (Hg, Ln, Ru) can produce common toxic symptoms in crops such as *Vigna radiata* (mung bean). These symptoms include chlorosis, reduced biomass accumulation, inhibition of growth, and impaired nutrient assimilation, ultimately leading to plant death (Pourrut *et al.*, 2011; Parihar *et al.*, 2015). Heavy metals impact almost all plant tissues and stages of the plant life cycle, from seed germination to senescence. In leaves, heavy metal toxicity affects leaf area, number, pigmentation, and thickness, disrupting plant water relations and various physiological processes such as transpiration and photosynthesis (Singh *et al.*, 2016).

Aluminum and zinc have distinct effects on *Vigna radiata*. Aluminum at low concentrations can promote root growth, but at high concentrations, it exhibits adverse effects, with root length showing a greater reduction compared to shoot length (Ali *et al.*, 2019; Hassan *et al.*, 2019). Zinc deficiency in mung beans leads to short internodes, decreased leaf size, and delayed maturity. However, high concentrations of zinc can cause toxicity, adversely affecting the plant's metabolic and cytological activities (Ghani, 2011; Khan *et al.*, 2018).

Materials and Methods:

Soil collection

Soil samples were collected from the central nursery in Bhawanipatna, Raisingpur, located in Kalahandi district.

Sterilization of seed material

Healthy mung bean seeds were sterilized with 90% alcohol for 5 minutes, followed by washing with distilled water and drying with filter paper.

Germination and growth of seeds

For germination analysis, seeds were planted in soil and monitored for germination percentage, number of seeds germinated, shoot length (hypocotyl and epicotyl lengths), and biochemical parameters such as chlorophyll and carbohydrate content. Nursery soil mixed with compost and garden soil was collected and distributed equally among 9 pots. Eight pots were treated with varying concentrations of zinc sulfate ($ZnSO_4$) and aluminum sulfate ($Al_2(SO_4)_3$) (50mg, 100mg, 150mg, 200mg), while one pot served as the control without metal treatment. Each pot received 20 sterilized seeds, ensuring equal spacing between seeds. Water was added at regular intervals to all pots.

Methods for analysis of different biochemical parameters

Estimation of chlorophyll

Fresh leaves from both metal-treated and control plants were collected. Chlorophyll was extracted using Arnon's method (1949). Leaves (100mg) were homogenized in 10ml of 80% acetone and centrifuged at 4000 rpm for 10 minutes. The supernatant's absorbance was recorded at 663nm, 645nm, and 470nm against an acetone blank. Chlorophyll content was calculated using the following formulas:

- Chlorophyll a (mg/g) = $\{(12.7 \times A663) - (2.69 \times A645)\}\ V/1000 \times W$
- Chlorophyll b (mg/g) = $\{(22.9 \times A645) - (4.68 \times A663)\}\ V/1000 \times W$

Where V is the volume of the extract in ml, and W is the weight of the leaf tissue in g.

Estimation of carbohydrates

Fresh leaves (100mg) were homogenized in 20ml distilled water. For carbohydrate estimation, a phenol-sulfuric acid method was used. The extract (1ml) was mixed with 1ml of 5% phenol solution and 5ml sulfuric acid, then heated in a water bath at 65°C for 10 minutes. After cooling, the sample turned golden yellow, and absorbance was measured at 485nm. Carbohydrate concentration was determined using a standard curve and expressed in µg/ml of fresh leaf extract.

Results:

Effects of zinc and aluminium on seed germination and growth in soil:

After few days of sowing the seeds, it started the germination then healthy and rapid growth of the hypocotyls and epicotyls occurred. The estimation measures are mentioned below.

Table 1: Effect of Zinc on seed germination and growth in pot

Seed germination per day					
Metal conc. Mg/kg soil	**DAY 01**	**DAY 02**	**DAY 03**	**DAY 04**	**DAY 05**
0	10	12	15	17	20
50	09	13	16	18	20
100	06	09	13	16	18
150	05	07	10	12	15
200	03	06	08	11	13

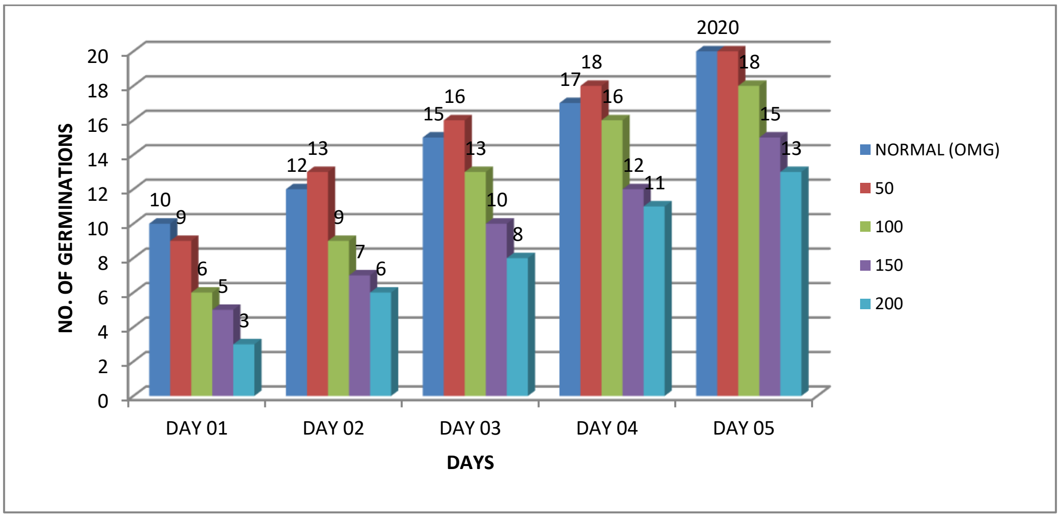

Fig 1: Effect of Zinc on seed germination per day

Table 2: Effect of Aluminium on seed germination and growth in pot

Conc. used (mg/kg)	**Seed germination per day**				
	Day 01	**Day 02**	**Day 03**	**Day 04**	**Day 05**
0	09	11	14	19	20
50	08	12	15	17	18
100	05	07	11	15	17
150	03	06	08	11	14
200	02	04	07	10	11

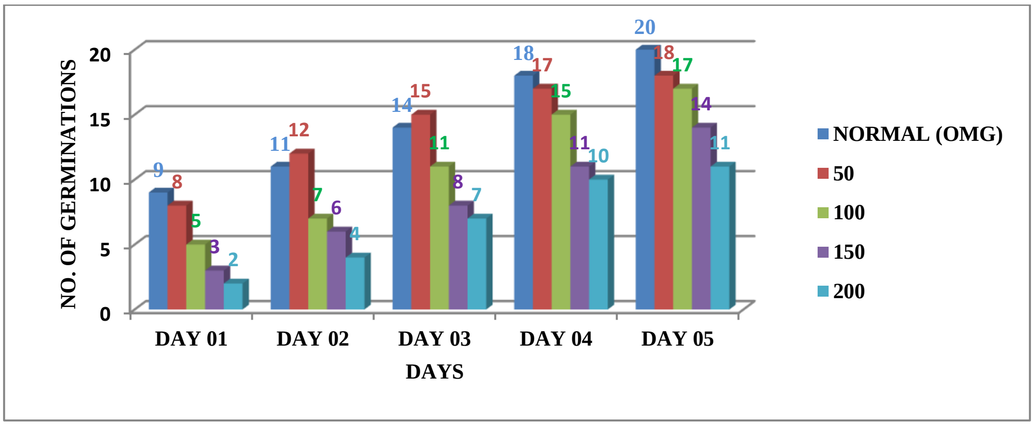

Fig. 2: Effect of Aluminium on seed germination per day

Table 3: Hypocotyl lengths (in cm) of zinc treated plants

Concentration (mg/kg)	Day 05	Day 10
0	10.16	14.35
50	9.04	12.41
100	8.36	11.27
150	7.88	9.51
200	5.47	7.68

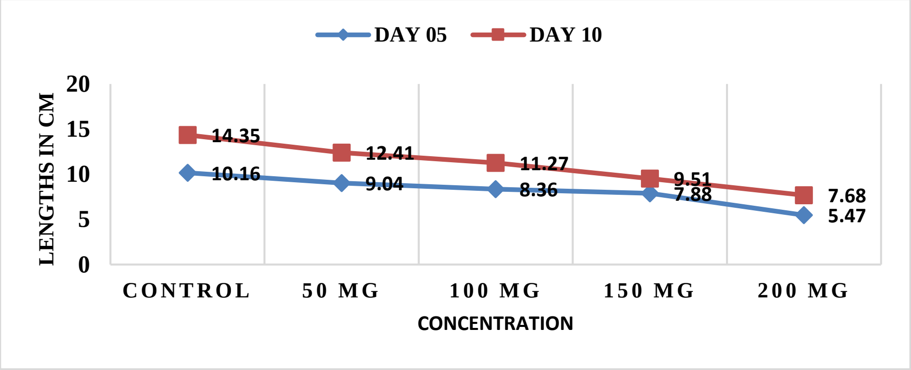

Fig. 3: Effect of Zinc on hypocotyl length

Table 4: Hypocotyl lengths (in cm) of aluminium treated plants

Concentration (mg/kg)	Day 05	Day 10
0	10.16	14.35
50	8.33	10.30
100	7.21	9.27
150	4.62	5.12
200	2.52	3.41

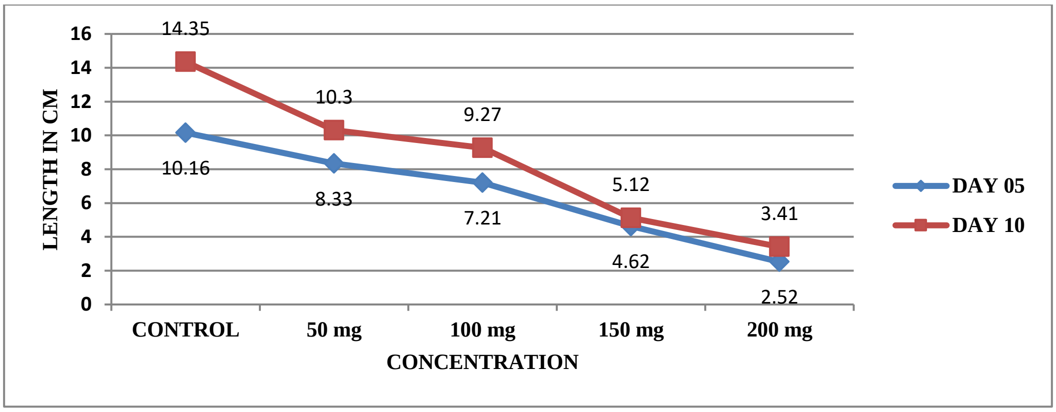

Fig. 4: Effect of Aluminium in hypocotyl length

Table 5: Epicotyl lengths (in cm) zinc treated plants

Concentration (mg/kg)	Day 05	Day 10
0	9.82	12.38
50	8.12	10.29
100	7.65	9.00
150	6.94	8.45
200	4.81	5.48

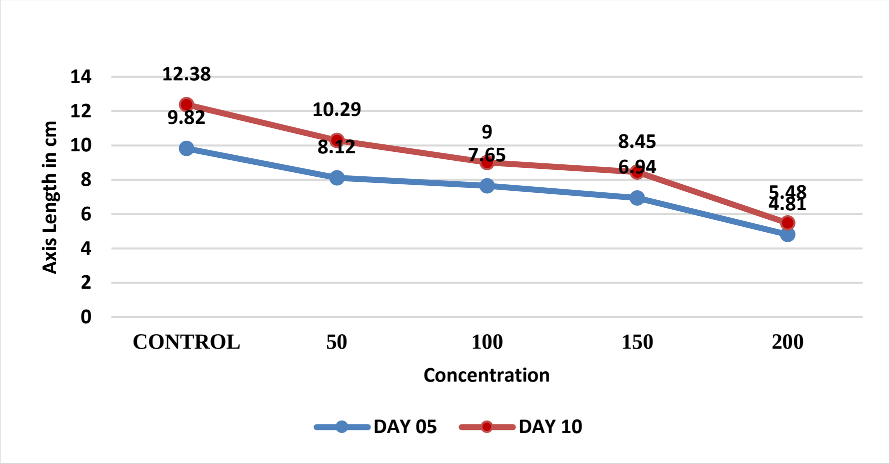

Fig. 5: Effect of Zinc treated plants

Table 6: Epicotyl lengths (in cm) aluminium treated plants

Concentration (mg/kg)	Day 05	Day 10
0	9.32	12.38
50	7.33	9.21
100	6.54	9.30
150	5.54	7.46
200	3.82	4.36

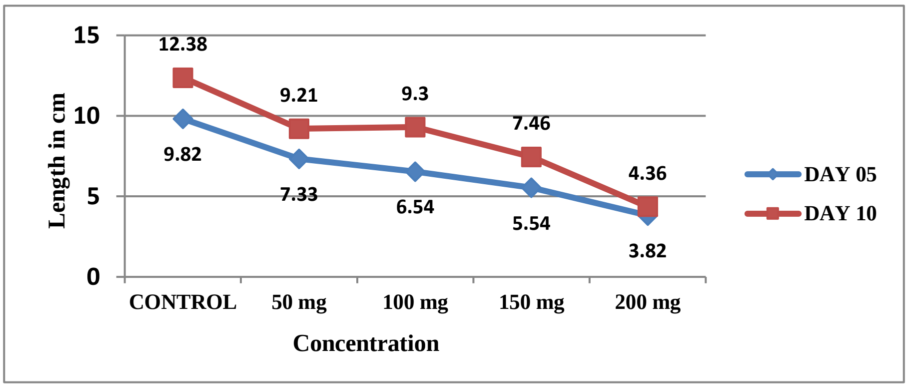

Fig. 6: Effect of aluminium in epicotyl length.

Table 7: Axis lengths (in cm) of zinc treated plant

Concentration (mg/kg)	Day 05	Day 10
0	19.98	26.73
50	17.16	22.7
100	16.01	21.41
150	14.82	17.96
200	10.28	13.16

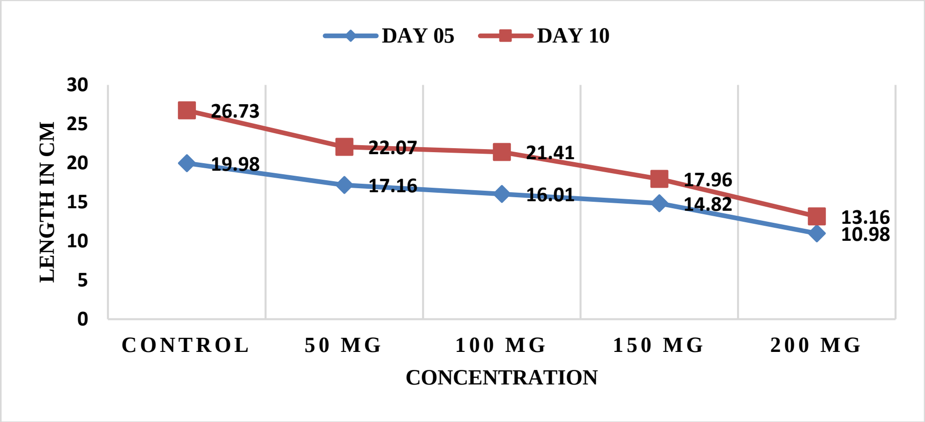

Fig. 7: Effect of Zinc on axis length

Table 8: Axis lengths (in cm) of aluminium treated plant

Concentration (mg/kg)	Day 05	Day 10
0	19.48	26.73
50	15.66	19.51
100	13.75	18.57
150	10.16	12.58
200	6.34	7.77

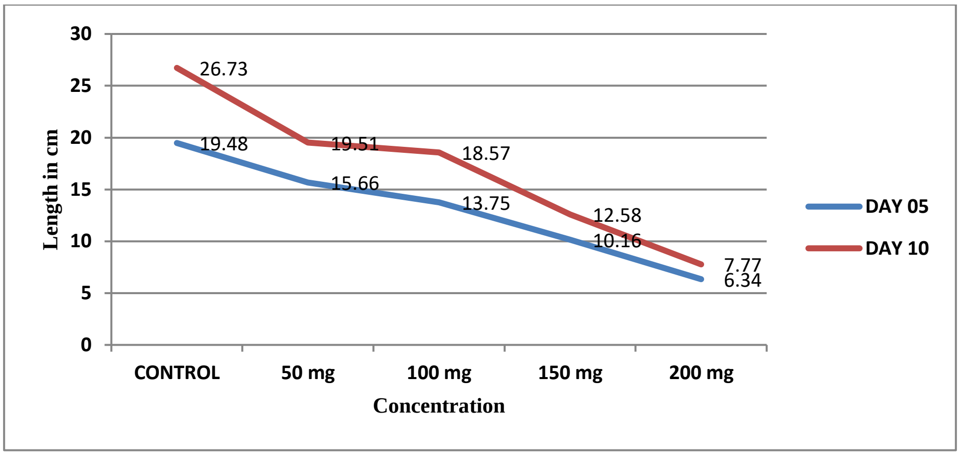

Fig. 8: Effect of Aluminium in axis length

Biochemical analysis of plants under stress

From this work we found the result of different biochemical parameters. Such as presence of chlorophyll content and carbohydrate content in both Zinc and Aluminium metal treated plants which are mention in below table.

Table 9: Estimation of chlorophyll content under Zinc sulphate

Sl. No	**Chemical Name**	**Conc.**	**Absorbance at**			**Chl. ‘’a’’**	**Chl. ‘’b’’**	**Total chl. (a + b) mg/kg**
			485 nm	**645 nm**	**663 nm**			
1	**$ZnSo_4$**	**Control**	0.409	0.152	0.203	0.0021	0.0025	0.0469
2		**50 mg**	0.380	0.094	0.291	0.0034	0.0018	0.0423
3		**100 mg**	0.379	0.104	0.172	0.0019	0.0016	0.0348
4		**150 mg**	0.262	0.054	0.070	0.0017	0.0014	0.0165
5		**200 mg**	0.364	0.103	0.160	0.0007	0.0009	0.0336

Table 10: Estimation of chlorophyll content under Aluminium sulphate

Sl. No	**Chemical Name**	**Conc.**	**Absorbance at**			**Chl. ‘’a’’**	**Chl. ‘’b’’**	**Total chl. (a + b) mg/kg**
			485 nm	**645 nm**	**663 nm**			
1	**$Al_2(SO_4)_3$**	**Control**	0.409	0.152	0.203	0.00287	0.00334	0.0473
2		**50 mg**	0.444	0.201	0.269	0.00216	0.00253	0.0621
3		**100 mg**	0.439	0.152	0.199	0.00211	0.00214	0.0466
4		**150 mg**	0.380	0.076	0.119	0.00153	0.00178	0.0248
5		**200 mg**	0.386	0.104	0.143	0.00130	0.00121	0.0324

Table 11: Estimation of carbohydrate content under Zinc

Measuring Parameters	**Control**	**Metal Concentration**			
	0 mg	**50 mg**	**100 mg**	**150 mg**	**200 mg**
Abs at 485 nm	2.030	1.745	1.540	1.311	1.148
Carbohydrate (mg/g)	20.978	15.163	9.062	8.625	6.170

Table 12: Estimation of carbohydrate content under Aluminium

Measuring Parameters	**Control**	**Metal Concentration**			
	0 mg	**50 mg**	**100 mg**	**150 mg**	**200 mg**
Abs at 485 nm	0.147	0.285	0.467	0.605	0.778
Carbohydrate (mg/g)	0.0010	0.0019	0.0030	0.0039	0.0050

Discussion:

This study investigates the toxicity of zinc and aluminum on *Vigna radiata* by analyzing various morphological and biochemical parameters. Heavy metal accumulation in the environment poses significant threats to all organisms. These metals enter the biosphere through both natural processes, such as volcanic eruptions and rock weathering, and anthropogenic activities, including mining, fossil fuel combustion, and sewage discharge (Nagajyoti *et al.*, 2010; Chibuike & Obiora, 2014). While certain metals like manganese (Mn), copper (Cu), and zinc (Zn) are essential micronutrients for plants, microorganisms, and animals, their excess can be detrimental (Hassan *et al.*, 2019).

The experiment revealed that zinc exhibits a dual effect on *Vigna radiata*. At optimal concentrations, zinc can positively influence plant growth, but higher concentrations lead to toxicity. This is evidenced by reduced shoot length, smaller leaf size, and decreased chlorophyll and carbohydrate content. Chlorophyll levels, typically ranging from 45.69 to 184.4 mg/kg, showed significant reduction under high zinc concentrations, corroborating the findings of Ali *et al.* (2019) and Singh *et al.* (2016). These results align with previous studies indicating zinc's beneficial role at low concentrations and its toxic effects at higher levels (Khan *et al.,* 2018).

Aluminum, unlike zinc, has no known beneficial role in plant growth and exhibits high toxicity even at moderate concentrations. Normal soil aluminum levels range from 5 to 10 mg/g, but in this study, aluminum concentrations of 50 mg/g caused marked reductions in shoot length and overall plant development. This supports the findings of Parihar *et al.* (2015), who reported similar adverse effects of aluminum on plant growth. The data from Tables 3.1 and 3.2 demonstrate that shoot length remains relatively stable at 50 mg/g aluminum concentration but decreases sharply at higher levels, indicating significant growth inhibition.

Furthermore, aluminum toxicity led to a notable decline in chlorophyll and carbohydrate contents. Chlorophyll measurements, which typically range from 0.076 to 0.444 nm at different wavelengths (663 nm, 645 nm, 470 nm), showed a substantial decrease, consistent with previous observations (Pourrut *et al.*, 2011).

Conclusion:

This study concluded that on the effects of heavy metal there is the loss of proper function in both morphological and physiological features. Decrease the length of plant. Increase in the concentration of heavy metals, decrease in the biochemical parameters. Chlorophyll and carbohydrate content is very negligible in the plant *Vigna radiata.* Seeds were damaged some leads to death after some days without germinate. Less amount of fresh weight of leaves was obtained so that their chlorophyll content also decreases. May be this metal has adverse effect to the soil. Concentration of Zinc and Aluminium probably affect the growth and development of the plant.

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ANALYSIS OF SOIL QUALITY USING PHYSICO-CHEMICAL PARAMETERS FROM SELECTED BLOCKS OF KALAHANDI DISTRICT, ODISHA

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Abstract:

This study examines the physico-chemical properties of soils from various blocks in Kalahandi district. Sixteen soil samples were analyzed for attributes such as color, pH, water holding capacity, moisture content, texture, and organic carbon content. Field visits and laboratory analyses revealed diverse soil colors (black, brown, reddish, grey), pH levels ranging from 5.43 to 8.8, moisture content from 1.85% to 21.3%, and water holding capacity between 6% and 42%. Soil textures varied from clay loam to sandy clay loam. Organic carbon content ranged from 0.12% to 0.73%, indicating a spectrum from low to high fertility. These findings provide valuable insights into the soil fertility status and will aid in the balanced application of fertilizers for sustainable crop production.

Keywords: Soil Quality, Physico-Chemical Properties, Kalahandi District

Introduction:

Plants are essential to all living things, thriving in soil to meet their daily needs. Soil is a vital natural resource, supporting crops that produce food and clothing. Beyond agriculture, soil plays a critical role in sustaining life by serving various ecological functions (Lal, 2010). It is a complex mixture of minerals, water, air, and living organisms, including the byproducts of their decomposition. This combination of elements forms the fine earth on the land's surface, created by rock weathering and the accumulation of mineral matter transported by ice, wind, or water (Brady & Weil, 2010). The process of soil formation, known as pedogenesis, involves interactions among the lithosphere, atmosphere, hydrosphere, and biosphere. Soil formation varies based on climate, underlying rock types, and the rate of weathering and biomass decomposition (Jenny, 2013).

Soil horizons and profile

Soil is stratified into distinct horizontal layers called horizons, collectively known as the soil profile. The main horizons, represented by the letters O, A, E, B, C, and R, each have unique characteristics. The O horizon is rich in organic matter, including decayed leaves, grasses, and surface organisms, giving it a dark brown or black color (Weil & Brady, 2017). The A horizon, or topsoil, is porous and rich in organic material and microorganisms, making it ideal for seed germination. Below this, the E horizon consists of leached nutrients, common in forested areas. The B horizon, or subsoil, is harder, containing minerals and metal salts like iron oxide. The C horizon comprises weathered bedrock, devoid of organic matter, and the R horizon is the unweathered bedrock layer (Wilding, Smeck, & Hall, 2012).

Soil types in Odisha

Odisha's soils are categorized into eight broad groups, encompassing four orders, ten suborders, and eighteen great groups.

1. **Red soil**: Covering 7.14 Mha, red soils are prevalent in districts like Koraput, Rayagada, and Keonjhar. These soils are rich in iron oxides, giving them a red color. The clay fraction mainly comprises kaolinites and illites (Pal *et al.,* 2014).
2. **Mixed red and yellow soil**: Occupying 5.5 Mha, these soils are found in districts such as Sambalpur and Bargarh. They vary in texture and depth, being coarser and shallower in uplands (Singh & Bhattacharyya, 2017).
3. **Black soil**: Found sporadically in districts like Puri and Ganjam, covering 0.96 Mha, these soils are heavy with more than 30% clay content, and their black color is due to the presence of titaniferous magnetite (Sharma & Bhattacharyya, 2015).
4. **Laterite soil**: Occupying 0.70 Mha, laterite soils are distributed in districts like Puri and Keonjhar. These soils are loamy sand to sandy loam with a hard clay pan in the subsoil, often acidic due to high aluminum and manganese content (Sahu *et al.,* 2013).
5. **Deltaic alluvial soil**: Covering 0.67 Mha in deltaic regions of rivers like the Mahanadi, these soils range from coarse sand to clay and have high water-holding capacity but slow permeability (Mandal, 2012).
6. **Coastal saline and alluvial soil**: Found in coastal districts such as Balasore and Ganjam, these soils are rich in soluble salts, predominantly clay to clay loam in texture (Kar, 2012).
7. **Brown forest soil**: Distributed in forest areas of Phulbani and Rayagada, covering 0.17 Mha, these soils are light-textured and acidic with medium to high organic matter (Sahoo *et al.,* 2018).
8. **Mixed red and black soil**: Found in western districts like Sambalpur, these soils are a mix of red and black, varying in texture and pH (Behera & Shukla, 2015).

Soil in Kalahandi

Kalahandi district features a mix of red, black, and sandy loam soils. Dominant soil types include red laterite, black clay, sandy loam, clay, and red sandy loam. These soils support various agricultural practices, contributing to the district's rich agricultural productivity (Mishra, 2016).

Nutrients in soil

Soil provides essential nutrients for plant growth and development. The major nutrients are nitrogen (N), phosphorus (P), and potassium (K), collectively known as the NPK trio. Other crucial nutrients include calcium (Ca), magnesium (Mg), and sulfur (S). Additionally, micronutrients like iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) are required in smaller amounts but are vital for plant health (Havlin *et al.,* 2013).

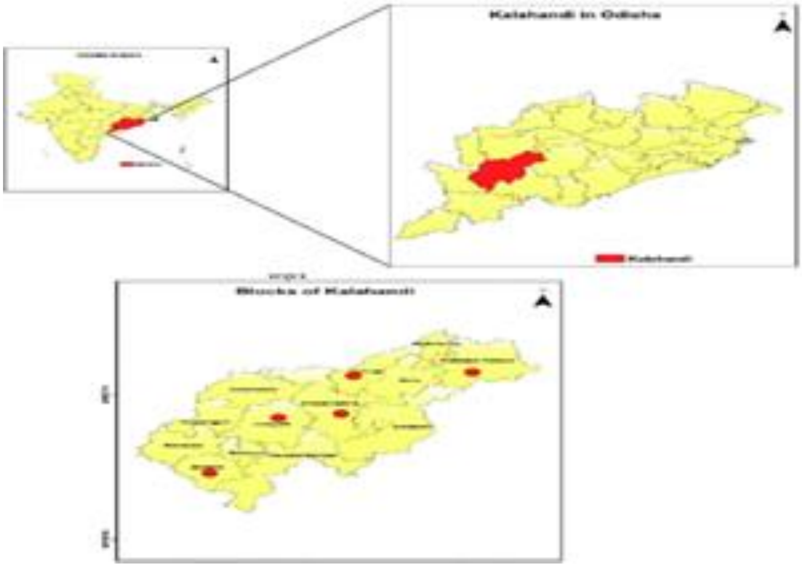

Fig. 1: Map of study site

Materials and Methods:

Collection of soil sample:

The soil sample was collected from the different block of Kalahandi district likely M. Rampur, Bhawanipatna, Kesinga, Jaipatna and Junagarh.

Fig. 2: Sampling site- Muding and Ghodapokhari of M. Rampur Block

Preparation of soil sample:

The sampling of soil is important for physico-chemical property analysis. There were a total of 16 samples collected with a depth of 5-20cm from January-February 2024. For sampling, first of all we removed the surface litter and also foreign materials like root, stones, pebbles, gravels etc. The soil sample arrived at the laboratory were labeled with sample number (S1, S2, S3……..S16).

Laboratory analysis:

The soil was analyzed for the colour, pH, water holding capacity, texture, moisture content and Organic Carbon Content as per standard laboratory procedure.

Results:

We have tested few physico-chemical parameters of soil: colour, pH, water holding capacity, texture, moisture content & organic carbon. From the above analysis we found following results:

Table 1: Result of all physico-chemical parameters of soil

Sl. No.	Soil sample	Colour	pH	Water holding capacity (for 50 ml pouring)	Texture	% of Moisture content	Organic carbon content
1	S1	Light brown	7.50	34 ml	Loam	10.13%	0.465%
2	S2	Yellow brown	7.95	40 ml	Sandy Loam	3.73%	0.585%
3	S3	Brown	8.12	38 ml	Sandy clay loam	9.31%	0.54%
4	S4	Faint grey	7.28	39 ml	Silt loam	12.53%	0.225%
5	S5	Creamy yellow	6.92	41 ml	Loam	2.79%	0.12%
6	S6	Black	8.08	36 ml	Loam	3.62%	0.375%
7	S7	Reddish brown	6.22	34 ml	Loam	1.85%	0.285%
8	S8	Faded brown	5.43	39 ml	Sandy clay loam	4.53%	0.075%
9	S9	Black	7.30	29 ml	Sandy clay loam	6.15%	0.69%
10	S10	Red	6.67	39 ml	Sandy loam	9.84%	0.81%
11	S11	Dark brown	8.42	41 ml	Clay loam	15.98%	0.735%
12	S12	Yellow brown	6.92	37 ml	Loam	11.63%	0.345%
13	S13	Dark brown	6.05	47 ml	Clay loam	21.38%	0.405%
14	S14	Light yellow brown	5.87	38 ml	Sandy clay loam	12.05%	0.93%
15	S15	Brown	8.88	38 ml	Loam	20.86%	0.375%
16	S16	Faint brown	8.06	39 ml	Loam	11.03%	0.465%

Discussion:

The study highlights the significant variations in soil types and their agricultural suitability across different villages in Kalahandi, Odisha. Brown soil, found in Ghodapokhari, Mathura, and Polkamunda villages, is rich in organic matter and minerals, which provides fertility and good drainage, making it ideal for diverse agricultural activities (Gupta *et al.*, 2018). This soil type supports crops such as wheat, sugarcane, and vegetables due to its balanced mix of clay, silt, sand, and organic matter (Lal, 2020).

Black soil, present in Maning and Podamundi villages, is renowned for its high fertility due to its substantial organic matter and mineral content, particularly magnesium and iron. This soil is highly productive for crops like cotton, soybeans, wheat, and millets (Singh *et al.*, 2016). The dark color of black soil is an indicator of its rich nutrient content, which supports robust plant growth (Brady & Weil, 2017).

Red soil, identified in Kinerkela, is characterized by its high iron oxide content, giving it a reddish hue. This soil type is prevalent in tropical and subtropical climates and is suitable for crops such as groundnut, cotton, soybeans, and tobacco (Mishra *et al.*, 2014). The presence of iron oxide enhances the soil's structure and nutrient retention capabilities, making it conducive for agriculture in regions with similar climatic conditions (Das *et al.*, 2021).

Soil pH significantly impacts nutrient availability and crop yield. The study found that soils with pH levels between 6.0 to 7.5 are optimal for crops like legumes, pulses, and spices (Jones *et al.*, 2015). In contrast, soils with pH outside this range can lead to nutrient deficiencies, adversely affecting crop growth (Marschner, 2012). For instance, soils in S8, S14, and S13, which fall within this pH range, support the cultivation of crops such as black gram, wheat, and various fruits (Tisdale *et al.*, 2022).

Water holding capacity (WHC) is another critical factor influencing soil suitability for agriculture. The study observed that soils in Kinerkela (S11) and Polkamunda (S13) have varying WHC, affecting their crop suitability. While S11's clayey soil is ideal for paddy and wheat, S13's lower WHC favors drought-tolerant crops like millet and sorghum (Hillel, 2013). Conversely, Podamundi's soil (S9) has a higher WHC, supporting crops with lower moisture needs, such as carrots and beetroot (Bouma, 2019).

Loamy soils in Maning, Sospadar, Ghatpada, Mathura, and Palas villages exhibit high nutrient and humus content with excellent drainage. These characteristics make loamy soils suitable for crops like wheat, sugarcane, and cotton (Stewart *et al.*, 2017). Sandy loam soils in Ghodapokhari and Kinerkela support crops like okra and pulses due to their good drainage and moderate fertility (Fageria, 2014). In contrast, silty loam soils in Muding are conducive for oilseeds and vegetables due to their balanced texture and fertility (Lal & Shukla, 2019).

Overall, the study underscores the importance of soil type, pH, WHC, and organic carbon content in determining agricultural suitability. Enhancing soil quality through the addition of organic matter can improve moisture content and fertility, thus supporting sustainable agricultural practices (Lal, 2015).

Conclusion:

The present study conducted on soil from 11 different villages across 5 blocks in Kalahandi district, situated in the western undulating agro-climatic zone of Odisha, aimed to assess soil suitability for agriculture. The goal of this soil analysis was to determine the optimal conditions for crop production through balanced fertilization practices. The findings underscore the importance of tailored fertilizer recommendations based on comprehensive soil test reports to maximize crop yield and quality. These insights are crucial for guiding agricultural practices towards sustainable productivity in the region.

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MILLETS: A SUPERFOOD FOR DIETARY, NUTRITIONAL, AND ECONOMIC SECURITY IN THE CONTEXT OF CLIMATE-RESILIENT AGRICULTURE

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Introduction:

The changing climate is leading to an increase in globalaverage temperature affecting agricultural production worldwide. Further, it directly influences biophysical factors such as plantand animal growth along with the different areas associated withfood processing and distribution. Assessment of effects of globalclimate changes and deployment of new tools and strategiesto mitigate their effect is crucial to maximizing agriculturalproduction to meet out food demands of the increasingpopulation. In this context, millet is most useful as it is anutritious, climate change-ready crop with enormous potentialfor yielding higher economic returns in marginal conditions incomparison with other cereals even in case of climate changewith harsh temperature conditions. Moreover, it has greaterceiling temperatures for grain yield and is an underutilized cropwith huge nutritional potential, which needs to be utilized fully (Satyavathi *et al.*, 2021).

Triggers for hunger can be addressed leading to a slight reduction in the population suffering from hunger and malnutrition from almost one billion in 1990–1992 to 850 million in 2010–2012, the threat of climate change and global warming still lingers. Estimates show that the reduction in food production rates along with the added pressure of feeding a population exceeding 9 billion by 2050 could lead to 2–3 billion people suffering from hunger, food and nutritional insecurities (Kumar *et al.*, 2022). Millets are multipurpose: They are one of the oldest foods which are small-seeded hardy crops that can grow well in dry zones or rain-fed areas under marginal conditions of soil fertility and moisture. Millets are grown in low-fertile, rain-fed, and mountainous areas. They are frequently referred to as super foods, and their production can be seen as an approach for a more sustainable and healthier world. Millets offer a wide range of benefits that can help to address key issues related to nutrition security, food security, and the well-being of farmers. Additionally, the unique characteristics of millets make them particularly well-suited to India's diverse agro-climatic conditions, contributing to their resilience as a crop.

Millets are smart food choice as they offer a multitude of benefits. They promote good health by providing essential nutrients, while also being environmentally sustainable due to their low water requirements and minimal carbon footprint. Additionally, millets are an excellent choice for farmers as they are highly adaptable to changing weather patterns, making them a reliable crop option. Millets provide food for over 90 million people in Asia and Africa. In contrast, wheat, rice, and maize are staple foods for 4 billion people. These three major cereals account for 51% of global calorie intake. Millets were once poor farmers' insurance against the vagaries of the Indian monsoon. Millets may be our future insurance against climate change. Millets are resistant to extreme weather conditions such as high temperatures and drought. They can grow in the most arid and harsh environments. Currently, around 55% of millets are grown in arid regions of Africa, 40% in Asia, and 3% in Europe. In India, the demand for millets has grown by 140% but the production is less than 50%.

Chart 1: Millets: an approach for sustainable agriculture and healthy world

Food Security	**Nutritional Security**	**Safety from diseases**	**Economic security**
1. Sustainable food source for combating hunger in changing world climate 2. Resistant to climate stress, pests and diseases	1. Rich in micronutrients like calcium, iron, zinc, iodine etc. 2. Rich in bioactive compounds 3. Better amino acid profile	1. Gluten free: a substitute for wheat in celiac diseases 2. Low GI: a good food for diabetic persons 3. Can help to combat cardiovascular diseases, anemia,	1. Climate resilient crop 2. Sustainable income source for farmers 3. Low investment needed for production 4. Value addition can lead to economic gains

Source: (Kumar *et al.* 2018); Abbreviation: GI, glycemic index

Millets are known for their climate-resilient features including adaptation to a wide range of ecological conditions, less irrigational requirements, better growth and productivity in low nutrient input conditions, less reliance on synthetic fertilizers, and minimum vulnerability to environmental stresses. o achieves inclusive and fair growth and development in our country, thesecond green revolution must focus primarily on nutrition, which was overlooked in the first green revolution, which was focused on production (yadav*et al.*, 2022). In our country, inner invisible hunger (micronutrient insufficiency) is a major issue. Eradication of extreme poverty and hunger is the first of the Millennium Development Goals (MGDs) proposed by the UnitedNations in the year 2000. India is far away from achieving this goal (Patwari, 2013). Further, cultivation of millets addressessome of the Sustainable Development Goals (SDG) such as SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health andwellbeing) and SDG 15 (life on land) (UN, 2021). Tackling these challenges necessitates a paradigm shift from the existingincremental adaptation strategies toward transformative substitutes that emphasize human health, nutrition, and environmentalsustainability. The current natural disasters make it even more imperative to shift toward a climate-resilient agriculture system (Bisoffi *et al.*, 2021).

Nutritional significance of millets

Millets are a group of highly nutritious small seeded grasses that are widely grown around the world as cereal crops or grains for fodder and human food. Millets are particularly important crops in Asia and Africa's semi-arid tropics, where they account for 97% of millet global production. Farmers in these regions prefer millets due to their ability to yield substantial harvests in a short period, despite dry and high-temperature conditions. As millets are primarily rain-fed crops grown in areas with low rainfall, they play a crucial role in promoting sustainable agriculture and ensuring food security in these regions. The world is in the clinch of a number of health problems and chronic diseases. The majority of these diseases are caused by a nutrient-imbalanced diet. According to UN Food and Agriculture Organization estimates, approximately 795 million people (10.9% of the global population in 2015) were undernourished. India's child wasting rate, at 19.3 percent, is the highest of any country in the world and drives up the region's average owing to India's large population. India has child stunting rates between 35 and 38 percent. According to the 2022 Global Hunger Index report, India ranked 107th among 121 countries (Von Grebmer *et al.,* 2022).

Protein energy malnutrition (PEM) was reported to result in 4, 69,000 deaths with 84,000 deaths from the deficiency of other vital nutrients such as iron, iodine and vitamin A (Lozano *et al.,* 2012). Obesity is also a major health concern in India with the prevalence rate of 11% in men and 15% in women. 60 million children under-weight (highest in world) 30% low birth weight babies75% pre-school children suffer from iron deficiency anaemia 85% districts have endemic iodine deficiency (Gragnolatia *et al.,* 2005) 35.7% of children under five are underweight; 58.4% of children between 6 and 59 months are anaemic; 53% of (non-pregnant) women are anaemic. 51 million people suffer from diabetes which is expected to increase to 79.4 million by 2030 (the increasing consumption of highly polished rice grains and decreasing consumption of coarse cereals contributes to this trend) 18.5% children over weight 5.3% children obese (Kaveeshvar and Cornwall, 2014). The millets contain as high as13-38% of total dietary fiber that could be considered in the management of disorders like diabetes mellitus, obesity, hyperlipidemia, etc.

Finger millet (*Eleusine coracana* L.), ragi or mandua is one of the important millets grown widely in various regions of India and Africa. Regarding protein (6-8%) and fat (1-2%) it is equivalent to rice and with respect to mineral and micronutrient contents it is superior to rice and wheat. Nutritionally; it has high content of calcium (344 mg/100g), dietary fibre (15-20%) and phenolic compounds (0.3–3%). Finger millet contains important amino acids viz isoleucine, leucine, methionine and phenyl alanine which are deficient in other starchy meals. Finger millet is conjointly acknowledged for many health benefits such as anti-diabetic, antitumerogenic, atherosclerogenic effects (Ganapathy and Patil, 2017).

Foxtail millet (*Setaria italica* L.), also known as Italian millet, is high in carbohydrates. When compared to rice, it has twice as much protein. It contains minerals such as copper and iron. It provides a host of nutrients, has a sweet nutty flavour and is one of the most digestible and non – allergic grains. Its protein characterisation showed as a potential functional food ingredient and the essential amino acid pattern rich in lysine suggest a possible use as a supplementary protein source. This millet oil could be a good source of natural oil rich in linoleic acid and tocopherols (liang *et al.,* 2010).

Kodo millet is high in vitamins, minerals, and sulfur-containing phytochemicals, as well as essential amino acids such as lysine, threonine, valine, and sulfur-containing amino acids (Bunkar *et al.,* 2021). Because of their high fibre content, polyphenols, and protein composition may significantly contribute to the nutritional security of a vast portion of the population

(Sharma *et al.*, 2017). Kodo millet has the highest dietary fibre concentration of any millet, making it an ideal food for diabetic patients. It also has a high protein content, a low fat content, a significant amount of vitamins like folic acid (B9), niacin (B3), pyridoxine (B6), and some minerals like calcium, iron, magnesium, potassium, and zinc (Saini *et al.*, 2021). Barnyard millet is considered a functional food crop due to its high vitamin content and antioxidant properties, and millet grains are gluten-free, providing strong potential for their usage as health foods (Sood *et al.*, 2015).

Proso millet the fat content is 2nd highest among millets i.e. 4.0g/100g and the predominant fatty acids in the free lipids are linoleic, oleic, and palmitic acids (Amadou *et al.*, 2013). The protein content is10.6 g/100g. The protein of proso millet is gluten free and can be used for foods for people with gluten intolerance or celiac disease. It is also a good source of Vitamin B2, B3 and B9. It is also rich in fibre and minerals i.e. 12g and 2.9 per 100g, respectively. Proso millet is also a god source of dietary fibre and has a lower glycaemic index (Park *et al.*, 2008).

Millets like Jowar has protein content of 10.4g, Bajra 11.6g, the 12.5g of proso millets, 12.3g of foxtail millet, and 11.6 of barnyard millet is equal to wheat’s 11.8g and significantly greater than rice’s 6.8g. In comparison to wheat and rice, finger millet has lower protein content (7.3g), but it is higher in mineral matter and calcium. Millets in general have more fibre than fine cereals. In compared to wheat 1.2g and rice 0.2g, tiny millets such as barnyard millet 14.7g, kodo millet 9g, little millet 8.6g, and foxtail millet 8.0g are the richest in fibre. As a result, millets are now referred to as "Miracle grains/ AdbhutAnaj and nutriacereals"(Senthilvel *et al.*, 2008). Finger millet has 16 times the calcium content of maize, and some believe it could eventually replace rice as a staple diet, which is especially important to humans due to the availability of key minerals (Hassan *et al.*, 2021).

Role of millets in sustainable agriculture and climate resilience

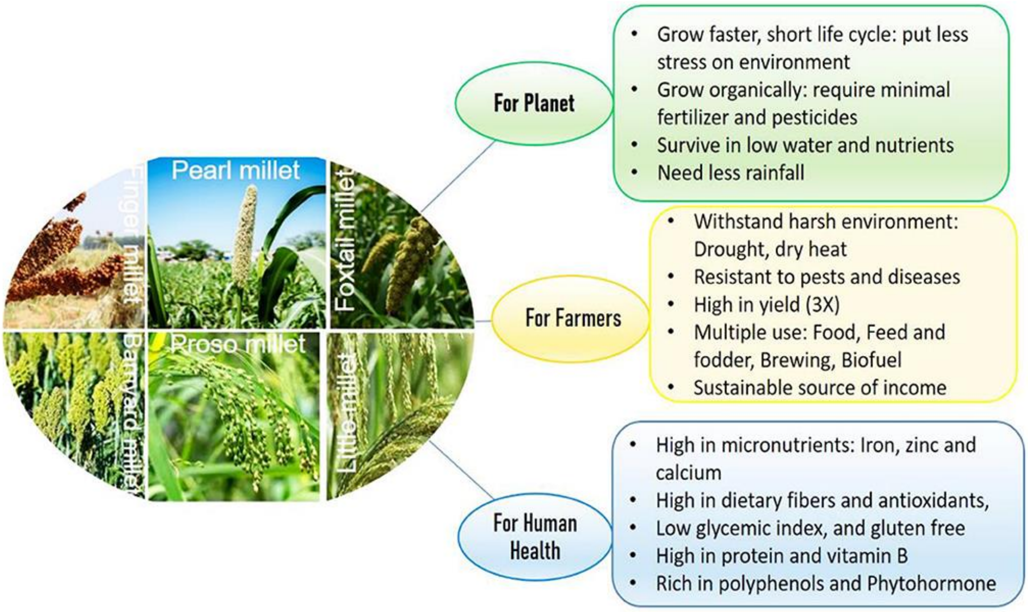

Fig. 1: Unique properties of millets for climate smart agriculture, ensuring human health, food and nutritional security (Source: Babele *et al.*, 2022)

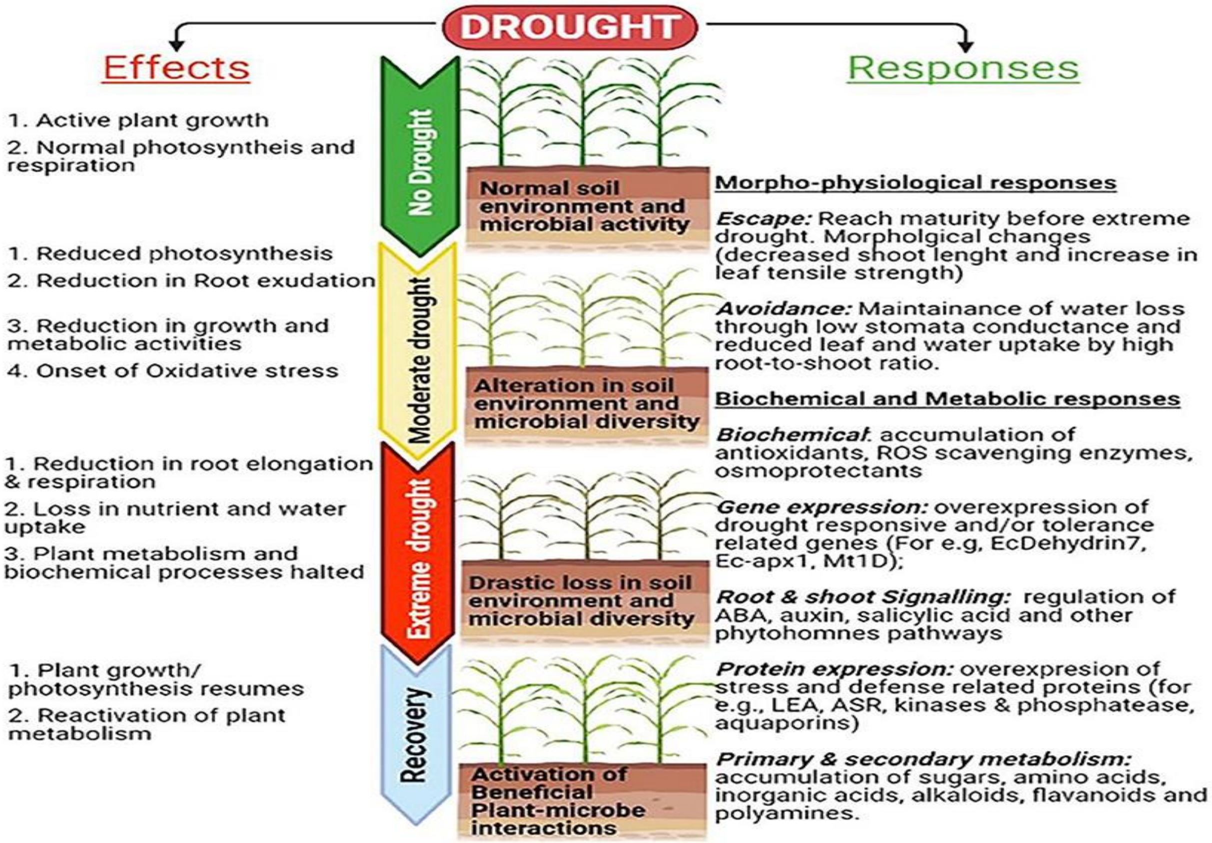

Fig. 2: **Drought responses and adaptive strategies linked to numerous morpho-physiological, molecular, and biochemical processes that confer better tolerance to environmental stresses in millets compared to major cereals.**

Millets and drought: Impact and adaptation

The productivity of crops can be influenced by various biological and environmental factors. Due to the rapid shifts in climate, significant areas of cultivable land have been lost, leading to the imposition of environmental stresses during critical stages of plant growth and development, resulting in decreased yields.The primary yield-limiting stressors in semi-arid and arid regions are abiotic stressors including drought, severe temperature (cold, frost, and heat), flooding, salinity, etc.Millets encompass numerous morpho-physioloical, biochemical and molecular traits that confer superior adaptation to drought than major cereals (figure 2). For example, the rainfall requirement of pearl and proso millet is 20 cm, which is many folds lower than rice as they require more than 120–140 cm (Kumar *et al.*, 2018). Among all major abiotic stresses, increased drought and heat due to climate change adversely affect current crop production and alone cause more annual losses. The climate change models predict that drought stress would continue as a major abiotic limitation for food production (Simmons *et al.*, 2020).

Millets short life cycle—10 to 12 weeks as compared to the 20 to 24 weeks of other major crops—also supports them in stress mitigation. Millets' photosynthetic rates are increased in warm weather, and they have an instantaneous water and nitrogen use efficiency that is 1.5 to 4 times higher than that of C3 plants. Also support them in stress mitigation. Several traits such as short stature, small leaf area, thickened cell walls, and dense root system also contribute to circumventing the stress and long-term consequences (Bandyopadhyay *et al.*, 2017). To produce 1 gram of dry biomass, Setariaitalica only needs 257 grams of water, whereas maize and wheat require 470 and 510 grams of water, respectively. Additionally, C4 photosynthesis provides secondary benefits to millets, including better growth and ecological performer in warm temperatures, enhanced flexible allocation patterns of biomass, and reduced hydraulic conductivity per unit leaf area (Lundgren *et al.*, 2014).

The integration of millets in Indian food supply chain

- To feed the population we first need to produce then only we can process millets and enjoy its nutritional benefits (Saleh *et al.*, 2013). Whereas the scope for enhancement of productivity under irrigated conditions is limited because of overexploitation of available resources, but there is ample opportunity for boosting yield in dry lands by adopting suitable crops and cropping systems. The combination of cereal and legume in intercropping can be a major help to the farmers in subsistence farming targeting livelihood security (Maitra, 2020). They also have numerous advantages, such as increased crop productivity, increased resource efficiency, reduced water run-off and soil conservation in erosion-prone areas, prevention of soil nutrient loss, improved soil health, insurance against crop failure due to unusual weather, and a higher monetary return and benefit-cost ratio (Maitra *et al.*, 2022).
- To meet the growing demand for healthy snacks among both children and adults, there is an effort to create nutritious snacks such as muffin cakes and biscuits using processed malted finger millet flour. This allows for maximum nutrient absorption due to the flour's bioavailability. One way to produce finger millet malt (FMM) involves steeping finger millet grains for 18-24 hours at room temperature and allowing them to sprout for 48-120 hours. Afterward, the grains are dehydrated at 60°C for 60 minutes, and the rootlets are removed. The remaining grains are then ground into flour for future use. Another approach to producing FMM involves blanching, pressure cooking, or roasting the grains. These methods can be repeated to produce high-quality finger millet flour that can be used in various snack recipes.
- After fermenting and cooking the ready-made mix to create idli and dosa, germinated powders of minor millets were blended and incorporated with other fundamental traditional components like rice powder and de-husked black gramme powder in defined proportions. In comparison to rice-based idli, high proportions of protein (15-18%), fat (8.5-9.8), and carbohydrate (69-72%) were determined for dosa. In millet based meals, processing stages such as decortication, germination, and fermentation also considerably reduced anti nutrients such phytic acids (69%) and tannin (78%) concentration (Krishnamoorthy *et al.*, 2013).
- A key caveat in achieving the estimated benefits of cereal diversification is the extent to which agronomic characteristics will permit switches between crops. On one hand, historical policy regimes have promoted the widespread cultivation of crops in places that may not

have otherwise been agro-ecologically suitable or sustainable (e.g., rice in northern India). On the other hand, certain areas where rice is currently grown may not be able to support the cultivation of coarse cereals. Assessments quantifying the range of biophysical conditions that can support the cultivation of each cereal will therefore be essential for understanding the potential magnitude of co-benefits from increased coarse cereal production (DeFries *et al.,* 2018).

- Increase in coarse cereals production has predominantly taken place in regions where these crops are traditionally grown. This presents a positive outlook for farmers as they can access local expertise and knowledge for efficient crop cultivation methods.

Conclusion:

The impacts of climate change have become increasingly evident in the environment, and this has posed significant challenges for the global agricultural sector. The occurrence of extreme climatic events such as rising temperatures, rainfall variability, drought, among others, exacerbates the existing pressures on agricultural and food systems. This outbreak has caused significant disruptions in many agriculture and supply chain activities, compounding food and nutrition security challenges, and sustaining livelihoods. Developing countries are disproportionately affected by the negative impacts of these climatic events, as they exacerbate resource-related issues such as water scarcity, pollution, and soil degradation. Despite the availability of a diverse range of landraces and varieties of millets, there has been a lack of focus on exploring their responsiveness to different soil types. This represents a significant untapped genetic resource that could potentially lead to the development of millet varieties that are better adapted to specific soil conditions. The low glycaemic index, gluten-free protein, and high mineral content (including calcium, iron, copper, and magnesium) of millets, along with their abundance of B vitamins and antioxidants, make them highly nutritious and well-suited as climate-resilient crops. These exceptional qualities contribute to their desirability as an important food source.Millets can serve not only as a source of income for farmers, but also as a means to enhance the overall health of communities.Hence, we propose the use of the term "climate smart/resilient" agriculture, taking into account various factors, such as: (i) Giving greater prominence to millet crops that are locally produced and considered significant, (ii) Boosting the production of nutrient-rich foods and increasing their value through processing to improve the human immune system, (iii) creation of low-cost farming systems that require less water and chemical inputs, (iv) Utilizing agro-ecology to integrate farming practices with the natural environment and (v) Encouraging consumer demand for climate-resilient grains and improving the feasibility of farming for small-scale and marginalized farmers.

By incorporating coarse cereals like millets and sorghum into crop production, food supply in India can become more nutritious, while reducing resource demand and greenhouse gas emissions, and enhance climate resilience without reducing calorie production or requiring additional land.Millets have the potential to contribute significantly to sustainable food systems under climate change, as they possess resilient qualities and the ability to survive in low water availability and stressful environments serves as a strong alternative to staple cereal crops

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OVERVIEW OF ORGANIC FARMING

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Introduction:

Organic farming is the modern method of indigenous farming. Organic farming keeps nature and environment in balance. In this, instead of using chemical fertilizers and pesticides, nutrients are given to the plants in the field through cow dung, compost, bacterial manure, crop residue, crop residue and naturally available minerals like rock phosphate, gypsum etc. The crop is protected from harmful insects and diseases by friendly insects, bacteria and biological pesticides available in nature.

Need for organic farming

At the time of independence, food grains were brought from other countries, very little was produced from farming, but with the unexpected increase in population, shortage of grains started to be felt. Then came the era of the Green Revolution. During this period, there was an unprecedented increase in food production in India between 1966-67 to 1990-91. To achieve the goal of producing more food grains, fertilizers, pesticides and chemicals were used indiscriminately, due to which the toxicity of the land also increased. Many useful bacteria were destroyed from the soil and its fertility also reduced. Today, due to lack of balanced fertilizers, production has become stagnant. Now even the pioneers of the Green Revolution have started accepting that excessive use of these chemicals has started creating many types of environmental problems and problems related to human, animal health and soil. The fertility of soil has started decreasing, due to which there is an imbalance of nutrients in the soil. Due to decreasing fertility of soil, it has become necessary to use more and more organic fertilizers to maintain the level of productivity.Currently, organic agriculture is commercially practiced in 120 countries, representing 31 million ha of certified croplands and pastures (~ 0.7 percent of global agricultural lands and an average of 4 percent in the European Union) and 62 million ha of certified wild lands for organic collection of bamboo shoots, wild berries, mushrooms and nuts (Willer and Youssefi, 2007). Several studies indicate that 10-60 percent more healthy fatty acids (like CLA's) and omega-3 fatty acids occur in organic dairy (Butler *et al.*, 2008). Biodynamic farms had better soil quality: greater in organic matter, content and microbial activity, more earthworms, better soil structure, lower bulk density, easier penetrability, and thicker topsoil (Reganold *et al.*, 1993).

Organic plant growth promoters:

Beejamrit

Material

- Cow dung – 5 kg
- Cow urine – 5 liters
- Lime- 50 grams
- Water – 20 liters
- 100 kg wheat seeds
- 50 grams forest soil

Seed treatment tips: Beejamrit is used for seed purification. Seed treatment means preparing the seeds to protect them from seed-borne or soil- borne diseases. Many diseases spread through seeds, from which it is very important to protect the crop. Treatment of pathogen diseases is possible only through seed purification. But even today most of the farmers sow their fields with untreated seeds. Seed treatment also increases the germination capacity of seeds. By seed treatment the seeds grow quickly and in good quantity. The roots grow rapidly and there is no outbreak of diseases on the crops from the ground.

Method of preparation: Take 20 liters of water in a vessel and add cow urine to it. Then cow dung, lime and soil from the base of the tree are mixed and the mixture is mixed well. Keep this mixture in shade for 24 hours. Then 100 kg seeds are spread on the floor or polythene sheet and seed nectar (Bijamarit) is sprayed on it. After spraying the seeds are mixed thoroughly by hand. So that a layer of seed nectar covers all the seeds.

Usage: Seed treatment should be done 24 hours before sowing. After using Beejamrit, dry the seeds in shade. Then sow the next morning. This treatment proves useful in the prevention of seed borne diseases.

Sanjeevak

In organic farming, sanjeevak is used to increase the number of microorganisms in the soil. To this the preparation and usage method is as follows:-

Material

- Cow urine – 3 liters
- Cow dung-30 kg
- Jaggery – 500 grams
- Water 100 liters

Allow to ferment for 10 days

Method of preparation: Mix the above mentioned ingredients thoroughly and let it rot in a tank for 10 days. Sanjeevak is ready after 10 days. By spreading it inside the field from all four sides and from the middle, the microorganisms spread completely in the field.

Usage: Sanjeevak is used at 1000 liters per acre in the first year, 800 liters per acre in the second year, 600 liters per acre in the third year. Additionally, application of 3 tonnes rotted cow dung per acre once every three years gives very good results to the crops.

Jeevamrit

Material

- Cow dung - 10 kg
- Cow urine - 5-10 liters
- Jaggery - 1 kg
- Gram flour (besan) - 1 kg
- A handful soil under the banyan(50 grams) or peepal tree -1kg
- Water- 200 liters

Method

Take 200 liters of water. Add 10 kg of local cow dung in it. Add 5-10 liters of cow urine. Add 1 kg of jaggery. Add 1 kg gram flour (pulse flour) and mix 1 handful of soil equal to 50 grams. Half quantity of ox or buffalo dung can be mixed with local cow dung. The fresher the local cow dung, the better, the older the local cow urine, the better. The cow's urine which gives more milk is less effective. A cow gives an average of 10 kg dung in a day, a bull gives 13 kg. Gives dung and buffalo gives 15 kg dung. Cow dung remains good for 7 days. A cow gives 3 liters of cow urine in a day. Bulls give 4 liters of urine and buffaloes give 5 liters of urine. As an alternative to jaggery, you can use 1 kg papaya, 1 kg banana or sugarcane juice.

In a plastic cement tank, cow dung is mixed well with cow urine, then jaggery is added to water and gram flour is added to the solution. At the end, add banyan tree soil and mix both the mixtures well. Let's mix. Keep this mixture in shade for 48 hours. Cover the tank with a sack. Jeevamrit is ready after 48 hours. Jeevamrit should be stirred with a stick 4 times in 48 hours. Jeevamrit can be used for 7 days.

The following microorganisms are available in abundance in Jeevamrit

Azospirillum

- P.S.M. (Phosphate solubilizing microbial) - 2 x 10 6
- Pseudomonas - 2 x 10 6
- Trichoderma - 2 x 10 6
- Yeast & Molds - 2 x 10

Precautions:

1. Keep Plastic and cement tanks in shade where there is no sunlight.
2. Do not keep cow urine in a metal vessel.
3. Use cow dung within 7 days and keep it in shade.
4. Apply Jeevamrit seeds for the first time with irrigation 21 days after sowing. Then it should apply every 21st day.

Usage: Use 200 liters of Jeevamrit per acre in the field in standing crop with water irrigation or with a spray machine at an interval of 15-20 days. 5-6 sprays are required for crop production. By using Jeevamrit, crops get proper nutrition and grains and fruits become healthy.

Panchgavya

Panchgavya is a special bio-enhancer prepared from five products obtained from cow, dung, urine, milk, curd etc. Maharajan, a physician and scientist at Tamil Nadu Agricultural University, has further refined the Panchasara formulation for the requirements of various horticultural and agricultural crops. The cost of production of Panchgavya is Rs 25-35 per litre. Panchagavya contains many useful microorganisms such as fungi, bacteria, actinomycetes and various micronutrients. This formulation acts as a tonic to enrich the soil, inducing vigor in the plant with quality production. The number of different microorganisms found in Panchgavya is as follows:

i) Total fungi: 38,800/ml.
ii) Total bacteria: 1,880,000/ml
iii) Lactobacillus: 2,260,000/ml
iv) Total anaerobes: 10,000/ml
v) Acid formers: 360/ml
vi) methanogen: 250/ml

Physico-chemical studies have shown that Panchgavya contains almost all the macro and micronutrients and growth hormones (IAA, GA) essential for plant growth. The abundance of fermentative microorganisms like yeast and Lactobacillus helps in improving the biological activity of the soil and helps in the growth of other microorganisms. 3-4% Panchgavya solution works effectively for spraying leaves. Best growth and productivity can be ensured by four to five foliar sprays: (a) two sprays before flowering at an interval of 15 days, and (b) two sprays during flowering and flowering at an interval of 10 days. and (c) one spray during fruit/pod maturity. Mango, guava, acid line, banana, spice turmeric, Flower-jasmine, Medicinal plants, like, Coleus, Ashwagandha, Vegetable (cucumber, spinach, okra, radish etc.)•The use of Panchagavya was found to be very effective in cereals (maize, green gram etc.), and many horticultural crops like sunflower etc. Since the use of Panchagavya causes a thin oily film to form on the leaves and stem, Therefore it reduces evaporation losses and ensures better utilization of the water used.

Material

- Cow dung solution - 4 kg
- Fresh cow dung – 1 kg
- Cow urine- 3 liters
- Cow's milk- 2 liters
- Curd- 2 liters
- Cow Ghee – 1 kg

Method of experiment: Use 3 liters of Panchgavya dissolved in 100 liters of water.

Use

- Seed and seedling treatment
- To increase soil fertility through irrigation water
- To enrich Panchgavya, banana fruits, cow's ghee, sugarcane juice, coconut water are added

Coconut-buttermilk batter

Material

- Cow Buttermilk - 5 Liters
- Coconut water – 1 liter
- Fruit juice- 1 liter
- Turmeric- 100 grams
- Hing- 20 grams
- It acts as an insecticide.

Method of preparation: First mix 1 liter of this solution with 10 liters of water and use it.

Use: to protect plants from fungal diseases and insects.

Neemastra (Organic pesticide)

- Add 5 kg of dry and crushed Neem leaves in water
- 5 litres of cow urine and 2 kg cow dung, ferment for 24 hours with occasional stirring, filter, squeeze and dilute to 100 liters.
- Use for foliar spraying in one acre.
- Useful for sucking insects and mite insects.

Brahmastra

- Crush 3 kg neem leaves in 10L cow urine.
- 2 kg custard leaves, 2 kg papaya leaves, 2 kg pomegranate leaves and Crush 2 kg guava leaves in water.
- Mix both and boil 5 times at the same interval till it reduces to half.
- Let sit for 24 hours, then squeeze out the extract.
- It can be stored in bottles for up to 6 months.
- Dilute 2-2.5 liters of this extract to 100 liters for one acre.

Benefits: Useful for sucking insects, fruit/flower borers.

Agnayatra

- 1 kilogram of Ipomoea (Besharam) leaves in 10 liters of cow urine, 500 grams chilli, 500 grams garlic and 5 kg of crushed neem leaves.
- Boil the mixture until it reduces to half. Filter and squeeze out.
- Store in glass or plastic bottles.
- Dilute 2-3 liters of extract to 100 liters and use it for one acre. Useful for leaf roller, stem/fruit/pod borer

Nectar (Amrit) water

There is a farmer group called Jeevit Mati Kisan Samiti in Kedia village of Jamui district of Bihar, where all the farmers are doing organic farming with the help of Amrit Pani, Brahmastra and Jeevamrit. It is the only one in Bihar which is registered under NPOP. And the village in which the products of the transition period are available in the markets. The demand for these products at the local level is increasing day by day.

Material

- Cow urine-1 liter
- Dung-1 kg
- Neem leaf-1 kg
- Gram flour-1 kg
- Jaggery- 150 grams
- Akwan leaf-1 kg

Method of preparation: Finely chop 1 kg each of Neem and Akwan (Calotropis) leaves. Mix 1 kg of fresh cow dung well in one litre of cow urine and dissolve 150 grams of jaggery in it and mix it. Add 10 liters of water to this mixture and mix 1 kg gram flour well. After that, put the chopped leaves of Neem and Akwan in the pitcher and mix the mixture well. After mixing the mixture well, the mouth of the pitcher is sealed with soil and cow dung. Keep it in a stable pitcher for 21 days. After 21 days, the nectar (Amrit) and water are separated from the mixture by filtering

Usage: Put 150 grams of nectar water in a 15 liter tank and spray it on the entire plant. Spraying it on crops at an interval of 15 days results in more fruits and flowers and also reduces the incidence of insects.

Economical and simple method of making organic fertilizer (compost) through home-made compost kit.

To prepare compost kit at home, the following items are required

- A hand drill machine
- A hand cultivator
- Coco peat –2 Kgs
- Any old bucket with lid of 20 liter capacity

In place of coco pit, such items which have the capacity to absorb moisture and completely decompose like old newspaper/cardboard/dry leaves/dung cake/dry stubble/other dry agricultural waste etc. can also be used.

Method of preparing compost kit:

First of all wash the bucket thoroughly, then make a sufficient number of holes in the bottom, walls and lid of the bucket with the help of a hand drill machine. After this, pour cocopitt in the bottom of the bucket that forms a one inch layer.

Method of making organic fertilizer:

Put one day's collected kitchen waste (vegetable or fruit peels/tea leaves etc.) in the prepared compost kit and mix with the help of a cultivator and cover the bucket with a lid. Next day, put the collected kitchen waste back in the same kit and mix it with the help of a hand cultivator and then add a little coco peat and cover it. Repeat this process daily, in about 3-4 weeks the manure/compost will be ready. There is no odor in the finished manure, it is light and brown/black in color when picked up in hand.

The use of green pesticides such as neem, compost tea and spinosad is environment-friendly and non-toxic. These pesticides help in identifying and removing diseased and dying plants in time and subsequently, increasing crop defense systems.

Organic farms' biodiversity increases resilience to climate change and weather unpredictability (Niggli *et al.*, 2008). Organic agriculture reduces erosion caused by wind and water as well as by overgrazing at a rate of 10 million hectares annually (Pimentel *et al.*, 1995).

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PRECISION AGRICULTURE TECHNOLOGIES FOR A SUSTAINABLE FUTURE

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Abstract:

Precision Agriculture (PA) is information and technology-based field management system to identify, analyse and manage spatial and temporal variability within the fields for optimal productivity and profitability, sustainability and protection of the land resource by minimizing the input costs. The benefit and effectiveness of using precision agricultural is highly depends on the capabilities of the utilization of PA technologies such as unmanned ground and aerial vehicle, GPS, GIS, remote sensing, yield mapping, VRT, soil and plant sensors, precision irrigation in day-to-day agricultural activities at the field. The integration of these technologies enables precise and data-driven decision-making, optimizing resource usage, enhancing crop yields, and promoting sustainable agricultural practices.

Keywords: Precision Agriculture, UGV, UAV, GPS, Remote Sensing, Yield Mapping

Introduction:

Precision agriculture (PA), precision farming or site-specific management (SSM) is a management system where crop production practices and inputs such as seed, water, fertilizers, herbicides and pesticides are variably applied within a field. Input rates depend on the needs for optimum production at each within-field location. Since over-application and under-application of agrochemicals are both minimized, this strategy has the potential for maximizing profitability and minimizing environmental impacts. Today, low-cost powerful computers, real-time controllers, variable rate application hardware, accurate location systems, and advances in sensor technology have combined to provide the technology to make PA a reality (Sahni *et al.*, 2018a). The precision farming approach to crop production may be viewed as a four-step process (Fig. 1). An initial step in this process is spatial measurement of those factors that limit or otherwise affect crop production and creation of database. These variability data are then used to develop a management plan for the variable application of inputs such as fertilizers and herbicides. Inputs are applied in precision field operations. Finally, the effectiveness of the PA system is evaluated with respect to economics and environmental impacts. This evaluation becomes a part of the data collection process for the next cropping season. Multiple iterations through the cycle allow for refinement of the precision management plan in succeeding seasons.

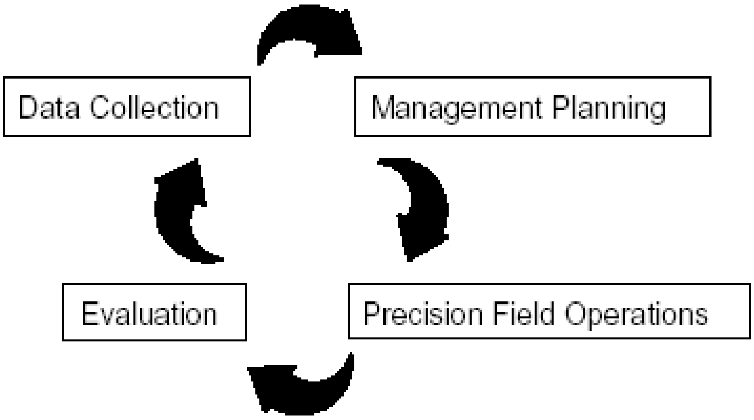


Fig. 1: Cyclic nature of the precision farming approach

Why precision agriculture?

The potential of using PA techniques for economic and environmental benefits could be seen through the reduced use of farm inputs such as seeds, water, fertilizers, herbicides and pesticides besides the minimized use of implements in the field. In PA, instead of managing the whole field based on some hypothetical average condition, which may not exist anywhere in the field, a site-specific differential approach are applied and inputs are applied accordingly. PA offers the possibility to automate and simplify the data collection and analysis and management of information. It allows to take management decisions quickly and implementation on smaller areas within the larger fields.

Advantage of precision agriculture

PA refers to the use of advanced technologies and data analytics to optimize various aspects of farming practices. The advantages of PA are numerous and can significantly improve efficiency, productivity, and sustainability in the agricultural sector. Below are some key advantages:

1. **Increased efficiency:** PA enables farmers to precisely manage resources such as water, fertilizers, and pesticides. This targeted approach ensures that inputs are used more efficiently, reducing waste and lowering production costs.
2. **Optimized crop yields:** By using data-driven insights, farmers can make informed decisions about planting, irrigation, and harvesting. This optimization leads to increased crop yields, as the right amount of inputs is applied at the right time and in the right location.
3. **Resource conservation:** PA helps conserve natural resources by minimizing the overuse of water, fertilizers, and pesticides. This not only benefits the environment but also contributes to cost savings for farmers.
4. **Cost reduction:** With better control over inputs and resources, farmers can reduce overall production costs. This includes savings on fuel, labor, and the cost of inputs such as fertilizers and pesticides.

5. **Improved crop quality:** PA allows farmers to monitor and manage factors affecting crop quality, such as soil conditions and nutrient levels. This can lead to the production of higher-quality crops, meeting market demands and potentially commanding higher prices.
6. **Data-driven decision-making:** PA relies on data collected from various sources, such as sensors, satellite imagery, and drones. Analyzing this data enables farmers to make informed decisions, optimize their practices, and adapt to changing conditions.
7. **Remote monitoring and automation:** Technologies like drones and sensors allow farmers to remotely monitor their fields. Automation, such as autonomous tractors and machinery, can perform tasks with precision, reducing the need for manual labor and improving overall efficiency.
8. **Risk management:** PA helps farmers identify and respond to risks more effectively. By monitoring weather patterns, soil conditions, and crop health, farmers can anticipate and mitigate potential challenges, such as diseases or adverse weather events.
9. **Environmental sustainability:** PA promotes sustainable farming practices by reducing the environmental impact of agriculture. By using inputs more efficiently and minimizing runoff, PA contributes to the long-term health of ecosystems.
10. **Data for continuous improvement:** The data collected through PA provides valuable insights over time. Farmers can use this information to continuously refine their practices, adapting to changing conditions and improving overall farm management.

PA offers a range of advantages that contribute to increased efficiency, sustainability, and profitability in modern farming practices. The integration of advanced technologies and data-driven decision-making is transforming agriculture into a more precise, adaptive, and sustainable industry.

Limitations of precision agriculture

PA, while offering numerous benefits, also has its limitations. Some of the key limitations are mentioned below:

1. **Initial cost and investment:** Implementing PA technologies can involve significant upfront costs for equipment, sensors, software, and training. This initial investment can be a barrier for smaller or resource-constrained farmers.
2. **Complexity and learning curve:** PA technologies often require a certain level of technical expertise. Farmers may need to acquire new skills to operate and interpret data from GPS-guided equipment, drones, and other technologies. This learning curve can be a challenge for some farmers, especially those with limited access to training and education.
3. **Data management and privacy concerns:** PA generates vast amounts of data related to crop yields, soil conditions, and other variables. Managing and analyzing this data can be a significant challenge. Additionally, there are concerns about the privacy and security of the data collected, as it may contain sensitive information about farm operations.
4. **Infrastructure and connectivity:** The successful implementation of PA relies on robust infrastructure and reliable connectivity. In remote or rural areas with limited access to

high-speed internet or cellular networks, farmers may face challenges in real-time data transmission and communication with smart devices.

5. **Standardization and interoperability:** The lack of industry-wide standards and interoperability between different PA technologies can hinder their seamless integration. Farmers may find it difficult to use equipment and software from different manufacturers together, leading to compatibility issues.
6. **Environmental impact:** While PA can enhance resource efficiency, there are concerns about the environmental impact of certain technologies. For example, the use of drones and sensor-equipped equipment may contribute to electronic waste, and excessive reliance on certain inputs (e.g., fertilizers, pesticides) could have environmental consequences.
7. **Dependence on external factors:** PA heavily relies on weather forecasts, satellite imagery, and other external data sources. Unpredictable weather conditions, inaccuracies in data, or technical malfunctions can impact the effectiveness of PA practices.
8. **Adoption challenges:** Convincing farmers to adopt PA practices can be a challenge. Resistance to change, skepticism about the benefits, and lack of awareness or understanding about technology can hinder widespread adoption.
9. **Scale of operations:** PA may be more suitable for larger farms with the financial resources to invest in advanced technologies. Small-scale or subsistence farmers may find it challenging to justify the costs and may not have the scale of operations to fully leverage the benefits.

Despite these limitations, ongoing advancements in technology and efforts to address these challenges are expected to contribute to the continued growth and improvement of PA practices.

Major precision farming technologies

Unmanned Ground Vehicles (UGV)

UGV refers to autonomous or remote-controlled vehicles designed for various tasks and operations on land without the need for a human operator on board (Fig. 2). These vehicles can range from small robotic platforms to larger, more complex machines and are equipped with sensors, cameras, and other technologies to navigate and interact with their environment. UGVs find applications in a diverse array of fields, including military operations, search and rescue missions, agriculture, industrial tasks, and more. The absence of a human operator on board distinguishes UGVs from traditional manned vehicles, offering advantages such as increased safety in hazardous environments, extended endurance, and the ability to perform repetitive or dangerous tasks without putting human operators at risk. Advances in artificial intelligence, sensor technologies, and communication systems have contributed to the development and evolution of UGVs. UGVs in agriculture refer to autonomous or remotely operated vehicles designed for various tasks related to farming and agricultural operations. These vehicles are equipped with advanced technologies, sensors, and control systems to perform tasks traditionally carried out by human operators or conventional machinery.

Fig. 2: UGV for precision application of agrochemicals

UGVs in agriculture are employed to enhance efficiency, reduce labor costs, and optimize resource utilization in various farming activities. The primary goal of UGV in agriculture is to revolutionize and optimize traditional farming practices through the integration of advanced technologies. These vehicles are designed to automate various tasks, ranging from planting and weeding to harvesting, reducing the dependency on manual labor and enhancing overall operational efficiency. By leveraging PA techniques, UGVs can precisely apply inputs such as fertilizers and pesticides (Fig. 3) based on real-time data, leading to resource optimization and minimized environmental impact. The overarching aim is to improve crop yields, reduce operational costs including transportation (Fig. 4), and contribute to sustainable farming practices. Additionally, UGVs enable farmers to remotely monitor and control agricultural activities, providing valuable insights for informed decision-making. As technology continues to advance, the goal is to establish UGVs as indispensable tools in modern agriculture, promoting increased productivity and environmental stewardship.

Fig. 3: Use of UGV for precision application of chemicals

Fig. 4: UGV used for transportation work in the orchard (https://www.xa.com/en/r150)

Unmanned Aerial Vehicles (UAV) or Drones

Unmanned aerial vehicles (UAV) or Drones have emerged as transformative tools in agriculture, revolutionizing various aspects of farming practices (Fig. 5). From crop monitoring and management to mapping and surveying (Fig. 6a), agrochemical spraying (Fig 6b), irrigation and water management (Fig. 6b), livestock management (Fig. 6c), and beyond, drones offer unparalleled capabilities that enhance efficiency, productivity, and sustainability in the agricultural sector. Through their aerial perspective and advanced imaging technologies, drones provide farmers with detailed and accurate information about their crops, soil conditions, water resources, and livestock. This data enables informed decision-making, precise resource allocation, and targeted interventions, leading to optimized yields, reduced input wastage, and improved farm management practices. Furthermore, the future possibilities of drones in agriculture are vast. As technology continues to advance, drones hold the potential to automate operations, analyze crop health, facilitate precision delivery, and integrate with other emerging technologies. However, challenges such as regulatory frameworks, cost considerations, data management, skilled workforce, and public perception must be addressed for widespread adoption and successful implementation of drone technology in Indian agriculture. Overcoming these challenges requires collaboration among stakeholders, investment in research and development, and proactive measures to ensure responsible and safe drone use.

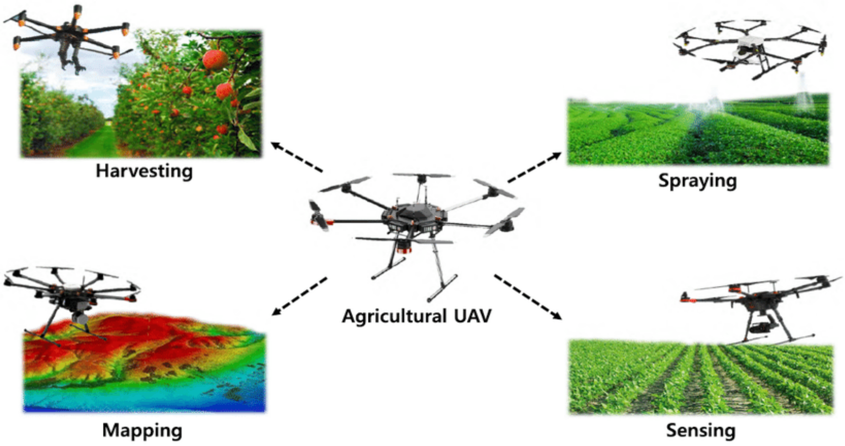
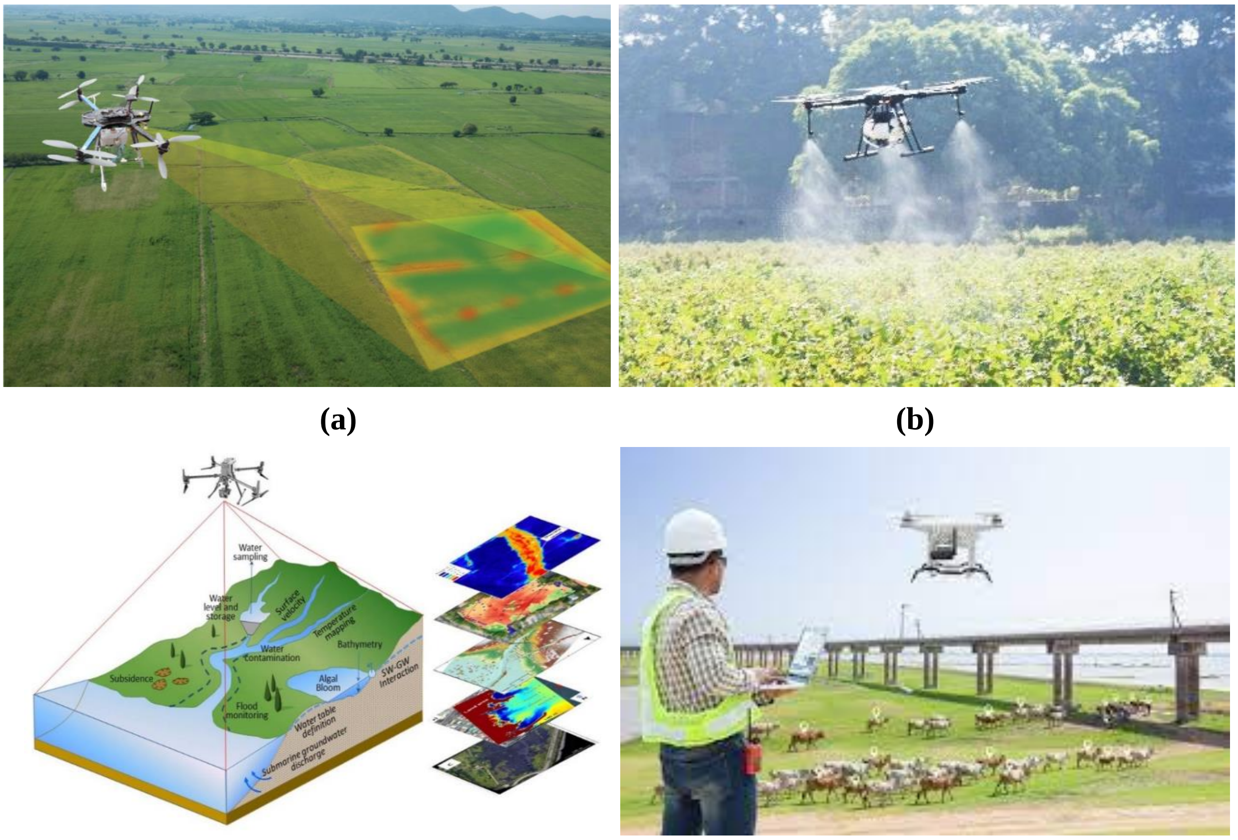


Fig. 5: Different applications of drone in agriculture



(a) **(b)**

(c) **(d)**

Fig. 6. Application of drone for (a) field mapping, (b) agrochemical spraying, (c) water management, and (d) livestock management.

Global Positioning System (GPS)

Almost all PA activities now use Global Positioning System (GPS) receivers to provide the spatial coordinates required to generate mapped information. Full availability of the GPS satellite constellation in the early 1990's was a key to enabling the effective measurement of within field spatial variability. The Global Positioning System is a satellite-based radio navigation system developed and operated by the U.S. Department of Defence that allows users to accurately determine their three-dimensional position and velocity anywhere in the world.

GPS provides continuous position information in real time, while in motion. Having precise location information at real time allows soil and crop parameter measurements to be mapped. GPS receivers, either carried to the field or mounted on implements allow users to return to specific locations to sample or treat those areas. GPS receiver with electronic yield monitors generally used to collect yield data across the land in a precise way. Global positioning systems (GPS) are widely available in the agricultural community. Farm uses include: variable rate planting (GPS + variable rate planting system), variable rate fertilizer application (GPS + variable rate controller), field mapping for records and insurance purposes (GPS + mapping software), mapping yields (GPS + combine yield monitor), and parallel swathing (GPS + navigation tool).

Geographic Information Systems (GIS)

Geographic information systems (GIS) are computer hardware and software that use feature attributes and location data to produce maps. An important function of an agricultural GIS is to store layers of information, such as yields, soil survey maps, remotely sensed data, crop scouting reports and soil nutrient levels. Geographically position data can be shown in the GIS, adding a visual perspective for interpretation. Besides data storage and display, the GIS can be used to evaluate present and alternative management practices by combining and manipulating data layers to produce an analysis of management scenarios. GIS is a very useful tool in developing model to relate various soil, environment and crop parameters to crop yield.

Remote sensing

Remote sensing is another technology, which holds promise for PA. A number of researchers and producers are already making use of aerial and satellite images to visualize variability within fields. It is a very useful tool for gathering much information simultaneously. It is the collection of data from a distance using sensors. Sensors can be of hand-held type, mounted on UAV, aircraft or satellite based. Remotely sensed data can offer a means for evaluation of crop health condition. Remote sensing technology has been mainly used for identifying crop stand problems and within-season crop stress such as may be caused by water or nutrient deficiency or pest infestation (Frazier *et al.,* 1997). This technology can reveal in-farm variability that affects the crop health and thereby production and can be timely enough to make the adjustment in management practice that increases production and profitability for the current crop.

Yield mapping/monitoring systems

The in-field variation of crop yield is an important input for site-specific decision-making. Crop yield is an integrator of the many varying crop and soil parameters, which are present, such as moisture, nutrients, pest problems, and many others. Linking spatial information on both yield and soil properties through a GIS system can allow for diagnostic determination of the predominant factor(s) controlling crop production. This then becomes the basis for developing precision input strategies. Also, yield measurements can provide feedback on the effect of variable rate application of inputs, allowing refinement of the application plan for future years. Yield sensors have been developed for crops such as potatoes, forage, and hay, but most yield sensing efforts have focused on grain crops. Yield monitors have been available for several years and the major grain combine manufacturers are also offering them as original equipment on their machines. In these systems, the grain leaving the clean grain elevator impacts against an instrumented plate, and the system relates this impact to a grain flow rate. When properly calibrated, yield monitor systems are usually very accurate (<1% to 5% error; Pierce *et al.*, 1997) at determining yield averages over large areas.

Variable Rate Technology (VRT)

The ability to precisely vary application rates while traversing a field is an essential part of precision farming. The variable rate technology (VRT) that makes this possible is probably the best-developed part of the integrated precision farming system (Tiwari *et al.*, 2019).

More recently, farm level controllers for VRT fertilizer application and herbicide application have become available. Other developments include VRT irrigation systems and VRT application of animal manures. Control decisions for variable rate application can be implemented either on-line or off-line. In the on-line or sensor-based approach, the controlled equipment incorporates on-board sensors, and the sensor data are used immediately for automatic control. In the off-line or map-based approach, data are collected and stored in one operation, and the controlled equipment uses the information in a separate field operation. The map-based approach allows more flexibility in data manipulation and pre-processing but requires that the location of equipment in the field be precisely defined, as with GPS. Most systems currently available are map-based, but more on-line systems will likely become available as real-time sensing technologies become more mature. Hybrid systems, which rely on a combination of both mapped and real-time data, may also come into more widespread use. Traditional uniform N applications, in most cases, result in over and under application of N in various parts of the field due to in-field spatial variability. The ability to variably apply optimum levels of N fertilizer and herbicides corresponding to site-specific field conditions has shown to increase N use efficiency, reduces wastage of herbicides, improve crop yields, crop quality, and net returns while decreasing nutrient overload. The VRT for fertilizer and herbicide application for weed control are shown in Fig. 7.

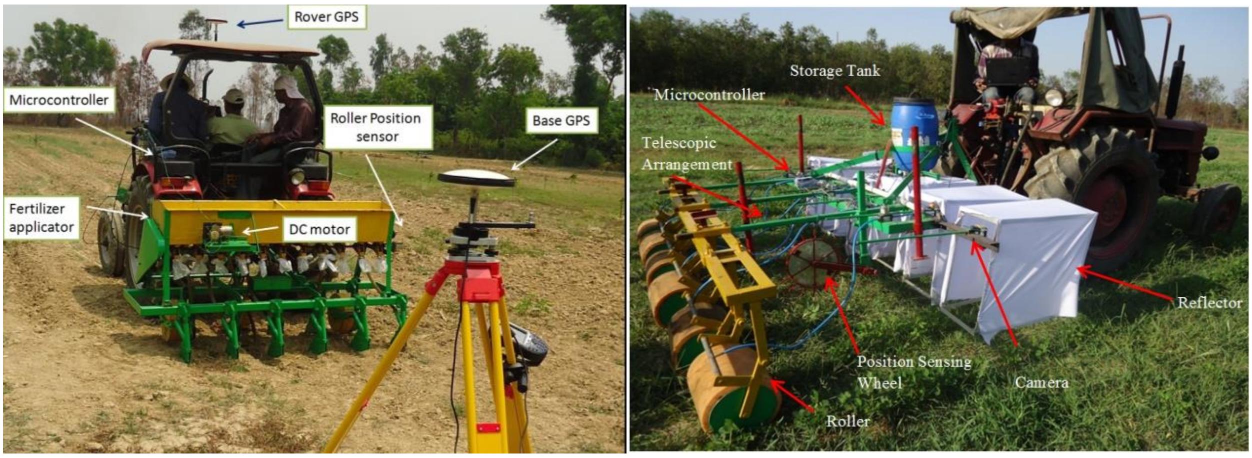


Fig. 7: "On-the-go" variable rate application of fertilizers and herbicides (Tewari *et al.*, 2014), Report of AIRCP on FIM, 2015, IIT Kharagpur)

Soil and plant sensors

Sensor technology along with advanced equipment improves the ability for input efficient farming in the environment-friendly way. Sensors can improve on the conventional methods used to derive agronomic recommendations. Compared to the conventional approach, sensors-based technology provides rapid and reproducible measurements of soil and plant conditions at field condition, they provide a cheaper alternative that avoids the problems imposed by time-consuming sparse sampling, sample transportation and preparation, and elaborate laboratory analyses. Sensors based technology provides farmers with effective tools for strategic on-farm testing to check conditions at critical stages in the growing season at different locations in their fields. Farmers can use sensed data to build site-specific databases that relate soil nutrient concentrations to plant reaction and crop development during the growing season, and ultimately to yield. Although this might take some time, this approach is more desirable than using the highly generalized generic data of the conventional procedures. Colour sensor is used for images of plant under controlled illumination to predict crop nitrogen content in field. This set up consists of a camera to capture the plant image, four lights to control illumination and a laptop for processing the signal. The results from the test were compared with the chlorophyll content of the crop measured using SPAD meter and the chemical analysis of plant leaf. The processing of the colour of plant image was done using MATLAB 7.0 program. Various features such as R, G, B, normalized 'r' and normalized 'g' were analysed for both the processes. This showed that the plant nitrogen content can be successfully estimated by its colour image feature. The complete system for estimation of plant nitrogen content using image processing is shown in Fig. 3.

Fig. 8a: SPAD metre and colour sensor for capturing the plant image in paddy field

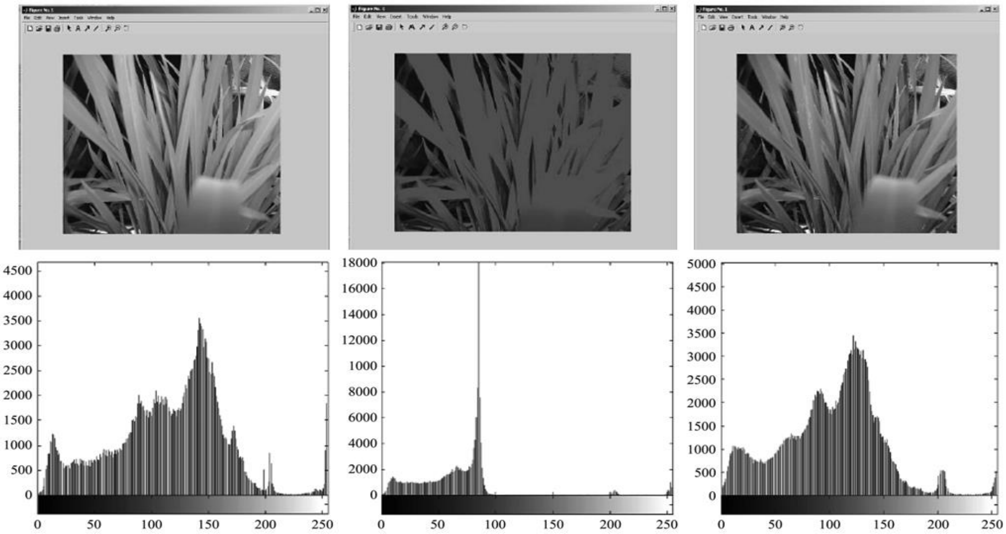


Fig. 8b: Original image, 'R' image and 'G' image of paddy plant

Fig. 8: Estimation of plant nitrogen content using digital image processing (Tewari *et al.*, 2013)

Precision irrigation

Precision irrigation is sustainable management of water resources which involves the application of water to the crop at the right time, right amount, right place, and right manner thereby helping to manage the field variability of water, in turn, increasing the crop productivity and water use efficiency along with the reduction in energy cost on irrigation (Kumar *et al.*, 2018). Traditional irrigation water management systems utilize the concept of uniform irrigation throughout the field whereas precision irrigation uses a system approach to achieve differential irrigation to crop under field variation (spatial and temporal).

The strategy for precision irrigation application is shown in Fig. 9. The first information needed for delineation of in-field spatial variability originates from the soil-yard maps. The next step is to obtain in-field information (small scale), which may come from utilization of fast, non-destructive real-time sensors, such as EM38, and the concept of surrogated properties, such as EC. This must be followed by soil sampling, based on the maps produced from this sensor, and correlate the surrogate property with the property in question (EC vs. AWC). Map for the management zones within the field (application map) for the field activity, here irrigation, showing the different quantities (depths) and their location within the field is established. Then a decision must be taken concerning the technologies that must be integrated with the present field machinery or need to be introduced, here, variable-rate technologies.

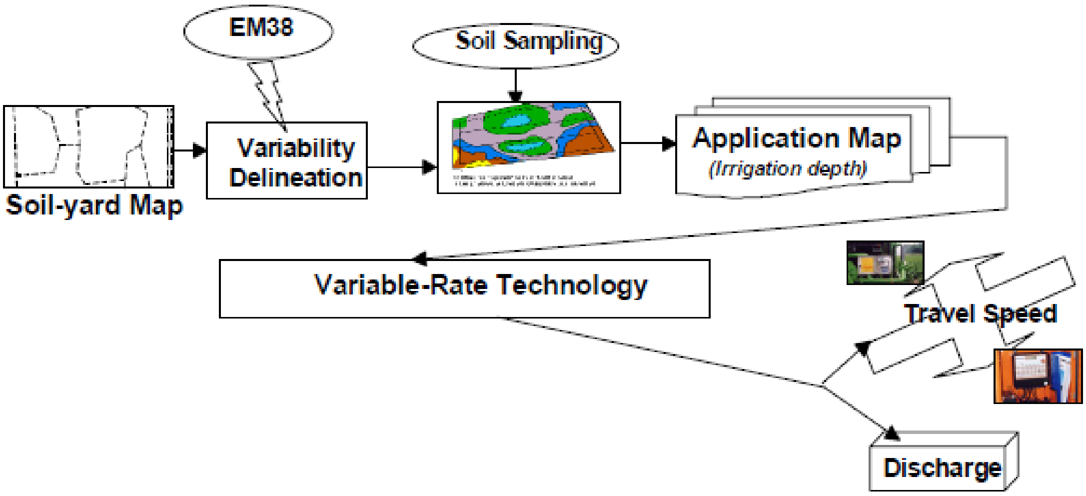


Fig. 9: Strategy for precision irrigation application in the field (Al-Karadsheh *et al.*, 2002)

Conclusion:

PA provides farmers with the ability to utilize crop inputs more effectively including farm equipment, seeds/seedlings, fertilizers, pesticides, and irrigation water. More effective use of inputs means greater crop yield and/or product quality, without polluting the environment. The amalgamation of advanced technologies not only empowers farmers with unprecedented levels of precision in decision-making but also propels agriculture towards a more sustainable and resilient future. However, it has proven difficult to determine the cost benefits of PA management.

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IMPROVEMENT OF FRUIT CROPS THROUGH PRECISION BREEDING

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Abstract:

Precision breeding emerged as a promising approach for the improvement of fruit crops, leveraging advancements in molecular biology, genomics, and bioinformatics. This chapter provides an overview of recent developments in precision breeding techniques and their applications in enhancing fruit crop traits, including yield, quality, and resistance to biotic and abiotic stresses. Here discussed the key methodologies employed in precision breeding, such as marker-assisted selection, genome editing, *etc*., highlighting their strengths and limitations. Furthermore, explored the potential challenges and future prospects of precision breeding in the context of fruit crop improvement, emphasizing the importance of integrating diverse strategies to accelerate breeding efforts and meet the growing demands of global agriculture.

Keywords: Precision Breeding, Fruits, Marker Assisted Selection (MAS), Genome Editing, Trans-Grafting.

Introduction:

Fruit crops play a crucial role in global food security and nutrition, providing essential vitamins, minerals, and antioxidants to human diets. However, traditional breeding methods often encounter challenges such as long breeding cycles, limited genetic variation, and unpredictable environmental factors. In this context, precision breeding has emerged as a promising approach to accelerate the development of improved fruit crop varieties with desirable traits. The current efforts are focused on increasing the crop productivity without using pesticides and fertilizers. Conventional breeding programs are often laborious, time consuming and difficult. Genetic engineering has greatly simplified the process of development of novel and improved varieties with better agronomic traits like disease resistance, abiotic stress tolerance, a better shelf life as well as improved crop productivity (Nerkar *et al.*, 2018). By leveraging cutting-edge molecular tools and genomics resources, precision breeding offers opportunities for targeted genetic modifications, efficient trait introgression, and accelerated breeding cycles. Biotechnological approaches give precision and dependability, and they are thought to shorten the breeding cycle in long juvenility crops. When dealing with cumbersome crops, the efficacy of procedures such as marker assisted selection, genomics, candidate gene, transgenics, and cisgenics has been demonstrated to be beneficial. DNA sequence-specific modification has become a powerful tool as molecular biology has progressed. The recent emergence of the novel plant breeding technologies like genome editing has opened up new doors for precise modification of the plant genomes without the introduction of foreign DNA (Altpeter *et al.*, 2016).

The global food security is largely affected by the changing climatic conditions, significant yield gaps between the actual yield and the potential yield, decrease in the number of farmers, lack of transportation infrastructure, post-harvest losses due to low shelf life of crops (Mackelprang and Lemaux, 2020; Fiaz and Wang, 2021). Precision breeding methods can help in addressing these problems by generating plants with sufficient yields in spite of changing climatic conditions. The fruit crop varieties which remain underutilized due to low yields, high disease susceptibility can be made more resilient using genome editing. They can make specific plants a source of essential nutrients that are lacking in the diets of some populations.

Parental screening for specific traits

Individual genotype performance

Ideotype breeding is based on the modification of plant architecture to reassemble the ideal ideotype (Khush, 2005). In practice, breeders take various decisions in order for their selection to resemble an ideotype. Advances in biotechnology and bioinformatics tools have been made easier for the breeder to select parents based on their phenotypic performance regarding specific traits in the plants. Kind of decision depends on the subjective goals of each breeder; they could select those genotypes with the best means for targeted characters like higher yield, vegetative and reproductive cycle, pest and disease resistance, salt tolerance, *etc*. However, it is not possible to capture the combining ability among parents based solely on their individual performance. The breeder must obtain crosses and evaluate the progenies or use techniques that allow the prediction of a specific genotype combination before the cross is performed (Mihaljevic *et al.,* 2005).

Adaptability and stability

Similar to the superior individual performance, parental selection for crosses can take into account high adaptability traits and yield stability. Considering these points, the selection of parents is also highly important for breeding programs for a broader area of coverage, mainly for locations that show distinct soil and climate conditions. Many statistical models were developed to make genotype x environment interactions more precise and to facilitate the understanding of adaptability and stability of evaluated genotypes. The main goal of analyzing the behavior of genotypes in macro regions (wide adaptability) and also in micro regions (specific adaptability), aiding the choice of parents for artificial crosses in breeding programs, as well as the recommendation of the best genotypes to farmers (Chloupek and Hrstkova 2005).

Diallel crosses

Diallel crosses represent the best strategy for determining the general (GCA) and specific (SCA) combining ability between putative parents. However, the major barrier for their use is the need of a large number of crosses for evaluation. The interpretation can be affected by the number and quality of data needed to obtain a precise estimate (Burow and Coors 1993). The increase in the number of genotypes used in the crosses can preclude the experiment feasibility and increase the difficulty in the analysis.

Top Crosses

One of the most efficient procedures for identifying parents with potential use for artificial crosses is the top cross. This procedure rapidly and precisely tests a large number of high-performance genotypes (elite lines, such as pure lines, open-pollinated, or synthetic populations) with a common genotype of wide or narrow genetic base, designated tester line. Therefore, it is possible to evaluate the general (GCA) or specific (SCA) combining ability of each genotype against a tester and to estimate the probable outcome of pair-wise combinations of the best genotypes by means of progeny tests.

Pedigree data

The use of pedigree data as a criterion for studying relationships between genotypes is not new in plant breeding. Malecot's co-ancestry coefficient was the first measure used to evaluate relationships between genotypes (Malecot, 1949). This coefficient was defined as the probability that two given alleles would be identical by descent in a genotype product of a given cross. This method is described as an easy and affordable alternative to be used for the selection of parental genotypes and it has been largely employed in genetic distance estimates.

DNA markers

The use of DNA markers in the estimation of genetic distances within and between plant species has grown rapidly in the last decade due to the development of excellent tools for scanning genetic information contained in plant genomes. Many different types of molecular markers are available today, being largely used for measuring genetic distances in many plant species. The main types of markers are: AFLP (amplified fragment length polymorphism), RFLP (restriction fragment length polymorphism), microsatellites, also known as SSRs (simple sequence repeats) and STS-PCR (sequence-tagged sitespolymerase chain reaction) (Dias *et al.*, 2004). RAPD (random amplified polymorphic DNA) have been shown to have low reliability and its use has diminished (Yang *et al.* 1996). However, to make more precise inferences about the available genotype pool, it is necessary to consider the properties of each marker and the genomic regions they assess. Examples of molecular-marker used in genetic distance studies are reported for many plant species of agronomic importance (Oliveira *et al.*, 1996; Zimmer *et al.*, 2003).

Genetic distance measure

The major tool used in estimating genetic distances is multivariate analysis. Genetic distance measures based on phenotypic characters and these are used to provide criteria for choosing parents. Genetic distance between genotypes is a way to predict the genetic variability among hybrid combinations (Cruz and Regazzi, 2001). However, in addition to genetic distance studies, it is also necessary that the genotypes selected for crosses possess high individual performance, adaptability and stability features for yield. When these requirements are fulfilled, there is a high probability of selecting transgressive genotypes due to the occurrence of heterosis and the action of complementary dominant genes (Carvalho *et al.*, 2001; Carvalho *et al.*, 2003).

High yielding, genetically distant genotypes may represent lines with distinct loci controlling the character and high combining ability

Methodologies in precision breeding

Marker-Assisted Selection (MAS)

DNA markers reveal sites and degrees of variation among individuals at the DNA sequence level (Jones *et al.,* 1997; Collard *et al.,* 2005). Marker-Assisted Selection (MAS) involves the identification and utilization of molecular markers linked to target traits of interest. Through marker-trait associations, breeders can select individuals with desired genotypes at early stages of the breeding process, thus reducing the time and resources required for trait evaluation. Recent advancements in high-throughput genotyping platforms and bioinformatics tools have facilitated the implementation of MAS in fruit crop breeding programs, enabling the introgression of complex traits such as disease resistance, fruit quality, and abiotic stress tolerance.

Genome-wide selection (GWS) allows for the evaluation of the value of parental potentials in a crossing plan. GWS makes use of genomic estimated breeding values (GEBVs) as selection parameters, rather than the estimated breeding values (EBVs) traditionally used by fruit breeders (Kumar *et al.,* 2012). GWS can be made particularly efficient and cost-effective if MAS is used for screening the cross-population with few markers to eliminate unwanted genotypes. This filtering then allows many thousands of markers to be used in order to apply the GWS (Kumar *et al.,* 2013). The foreground MAS selection in a breeding population for simple 'must-have traits', such as pest and disease resistances, flesh or skin colour, rootstock dwarfing ability as in apple and cherry, or gender in dioecious crops such as kiwifruit, enable a substantial reduction in the number of seedlings to be genotyped with dense markers for GWS (Gardiner *et al.,* 2014). It can be expected, perhaps not surprisingly, that the use of MAS could be distributed, in terms of effectiveness, in a contrasting way considering two important factors, such as the prediction of breeding value and the reduction of costs. Several studies have demonstrated the superiority of MAS in supporting breeding, particularly in academic studies, where technical resources are frequently available (Wannemuehler *et al.,* 2019). Some studies have examined the economic impacts of MAS in horticultural breeding programs. One study indicated that inheritance of the trait, the timing of trait expression, application timing of DNA testing in a program, and testing costs play important roles in determining cost-efficient MAS (Luby and Shaw, 2001). In a breeding program carried out on apple trees, in which the number of seedlings produced each year is very high (30,000), the break-even point (BEP) was evaluated by comparing a traditional selection method with one assisted by molecular markers. Pyramiding of multiple resistance alleles to produce durable resistance to a particular disease is difficult to achieve through TSS (Evans and James, 2003), as a resistant phenotype can rarely distinguish between one or multiple major-effect resistance alleles.

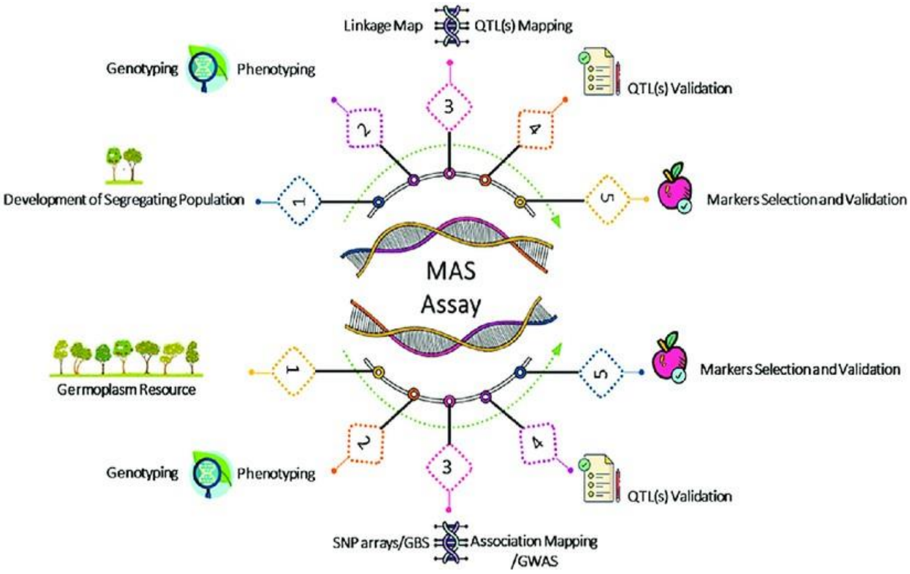

Fig. 1: Schematic workflow for marker assay development (Mori and Cipriani, 2023)

With traditional seedling selection (TSS), the identification of individuals with multiple resistance alleles to a disease usually involves extensive, laborious progeny testing (Bliss, 2010). MAS is more powerful than TSS in identifying seedlings carrying several resistance alleles for a disease as DNA markers can easily determine multiple allele presence whereas phenotyping cannot (Collard and Mackill, 2008; Bliss, 2010). DNA-based genotypes are independent of plant development stage, identification of seedlings predicted to be genetically superior for a trait can be performed on small, very young plants such as newly germinated seedlings in a greenhouse, and inferior individuals can be quickly filtered out (Foolad and Panthee, 2012).

Genetic engineering

Genetically engineered plants are altered by the inserting of one or more genes not limited by species or kingdom, allowing the introduction of desirable traits directly in an elite background in a single generation. The aim of genetic engineering is to improve important traits such as fruit yield or quality, or resistance to biotic or abiotic stress (Ricroch and Hénard-Damave, 2016; Yabor *et al.*, 2020). The first approved transgenic fruit (GMO) was the Flavr Savr tomato developed by Calgene, a biotechnology company later acquired by Monsanto (Redenbaugh *et al.*, 1992). The Flavr Savr variety expressed an antisense RNA to suppress the expression of β-polygalacturonase, the enzyme responsible for pectin degradation and therefore fruit softening, giving the fruits a longer shelf life. Flavr Savr was approved by the US Food and Drug Administration (FDA) in 1994. After tomato, the next transgenic fruit developed was papaya varieties (Sunset and Kapoho) in which the gene coding for capsid protein from Papaya Ringspot Virus (PRSV) was inserted into the papaya genome. In 1998 the first virus resistant transgenic papaya was released (Gonsalves, 2006). More recently, a transgenic non-browning apple has been approved for release in the USA based on the same principle (Igarashi *et al.*, 2016; Stowe and Dhingra, 2021). The transgenic approach has been used to improve fruit quality, firmness, growth habit, tolerance to biotic and abiotic stress in several fruit crops such as apple, pineapple, papaya and banana (Gonsalves, 2006; Igarashi *et al.,* 2016; Sreedharan et al.. 2013; Yabor *et al.*, 2020). Currently, the only transgenic fruit crops approved in the US are a papaya ring spot virus-resistant papaya (Gonsalves 2006), a plumpox virus-resistant plum (Scorza *et al.,* 2012), the non-browning apple (Xu, 2013) and a Pinkglow pineapple variety (FDA 2018).

Genome editing

Genome editing allows the introduction of mutations at pre-defined sites by targeting a particular unique sequence with a guided nuclease. This technique offers unparalleled precision and efficiency in gene manipulation, allowing breeders to create precise mutations or introduce novel alleles to enhance desired traits. In fruit crops, genome editing has been employed for various purposes, including the improvement of fruit shelf life, flavor enhancement, and the development of disease-resistant cultivars. Despite regulatory and ethical considerations, genome editing holds immense potential for accelerating trait improvement and addressing emerging challenges in fruit crop production. In the last decade, the arrival of genome editing has resulted in another leap forward in breeding technology (Jansing *et al.*, 2019; Ghogare *et al.*, 2020). Genome editing involves the expression of specialized nucleases that introduce double-strand breaks (DSBs) at precise and pre-selected targets in the plant genome. The inaccurate repair of these DSBs results in the formation of indels that inactivate the targeted gene, although the provision of donor DNA matching the flanks of the target site can achieve the integration of new sequences (analogous to transgene insertion, but more controlled) or the replacement of one sequence with another. Importantly, these processes leave no other footprints behind and at the sequence level, the indel mutants are indistinguishable from natural mutations or those induced by chemicals or radiation (Pérez-Massot *et al.* 2013; Zhu *et al.* 2017).

Various genome editing platforms have been described, but the three that have been used in fruit crops are zinc fnger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and the CRISPR/Cas9 system (Ghogare *et al.*, 2020; Shukla *et al.*, 2009; Zhang *et al.,* 2013). The principle of ZFNs and TALENs is similar. Both are based on the type IIS restriction endonuclease FokI, in which the sequence dependent DNA-binding domain and endonuclease domain are physically and functionally separate. Accordingly, the endonuclease domain cuts at a non-specific sequence a few nucleotides downstream of the specific target site (Zhang *et al.,* 2013). Unlike the protein-guided ZFNs and TALENs, the CRISPR/Cas9 system is based on a nuclease (Cas9) that recognizes a very short and therefore abundant sequence (3–8 nt long) known as the protospacer adjacent motif (PAM). However, the nuclease is guided to a more specifc target by a guide RNA (gRNA), which is a complementary sequence next to the PAM (Bortesi *et al.* 2016; Armario Najera *et al.* 2019).

Zinc fnger nucleases (ZFNs) have been used to edit selectable markers in apple and fig (Peer *et al.,* 2015); whereas TALENs have been used to enhance traits in several fruit crops (Khan *et al.*, 2017). However, these systems have only been used to a limited extent in fruit trees due to the complex principles of construct design (Carroll, 2011). CRISPR/Cas9 has been widely used to edit multiple fruit crops (Zhou *et al.,* 2020). For example, resistance to abiotic stress has been improved by using CRISPR/Cas9 in banana, grapevine and papaya (Tashkandi *et al.,* 2018; Tian *et al.,* 2018; Yin *et al.,* 2018). CRISPR/Cas9 has also been used for the domestication of ground cherry and kiwifruit varieties (Varkonyi-Gasic *et al.,* 2019; Zsögön *et al.,* 2018).

Trans-grafting

Grafting is a cultivation method that exploits the cooperative relationship between partner plants possessing different genomes (Mudge *et al.,* 2009). In apple cultivation, it has been used mainly for maintenance and propagation of clone strains, and for altering plant vigour, architecture, and precocity. Since the rootstock interacts with soil, it greatly affects the growth and production ability of the scion through water and mineral uptake. Trans-grafting refers to grafting a GM part with a non-GM part. The GM-root provides the potential of using transgenic rootstocks to improve the performance of commercially approved scion varieties, and produce non-GM products. Therefore, trans-grafted plants have the potential to address the public's concerns about transgene flow and exogenous transgene products in most transgenic organisms. As a matter of course, GM parts can be used for cisgenic (genetic modification by disusing a non-crossable species or a synthetic gene) strategies (Lusser *et al.,* 2012).

Mutation breeding

Mutations in plants are "any heritable change in the idiotypic constitution of sporophytic or gametophytic plant tissue, not caused by normal genetic recombination or segregation" (Harten, 1998). Mutation breeding is the purposeful application of mutations in plant breeding. Unlike hybridization and selection, mutation breeding has the advantage of improving a defect in an otherwise elite cultivar, without losing its agronomic and quality characteristics. Mutation breeding is the only straightforward alternative for improving seedless crops. These changes in our target plant can be passed on to progeny and used for human benefit through breeding. The occurrence of mutations within the genome of plants is rare, and in natural settings can be lethal. Through breeding and selection, beneficial mutants can be identified and used to improve target species. Resistance to black spot disease (*Alternaria alternata* pv. Japanese pear), considered to be the most serious disease in Japanese pear (*Pyrus serotina* var. culta), was induced in Japan in the 1960s through chronic irradiation of the cultivar 'Nijisseiki' and a resistant cultivar 'Gold-Nijisseiki' was released (Sanada *et al.,* 1988; Ahloowalia *et al.,* 2004). The success of this programme led to radiation breeding of susceptible 'Shinsui' and 'Osa-Nijisseiki' cultivars resulting in resistant cultivars 'Kotobuki-Shinsui' and 'Osa-Gold' (Masuda *et al.,* 1994; Nakagawa, 2009). The 'Osa-Gold' mutant has the added advantage of being self-compatible, eliminating the need to grow pollinators.

Back cross method

Backcross breeding is a useful method in fruit crop breeding aimed at incorporating specific traits from one parental line (the donor parent) into another well-adapted parental line (the recurrent parent), while still retaining most of the desirable characteristics of the recurrent parent. This method is particularly beneficial when the recurrent parent possesses desirable agronomic traits such as high yield, disease resistance, or superior fruit quality, but lacks certain specific traits present in the donor parent. The characteristic could be a trait, a gene or even an anonymous locus or chromosome segment. In successive generations, progeny are selected for the characteristic of interest and then backcrossed to the recurrent parent. This ensures that the proportion of genome from the donor parent tends to zero as generations accumulate, except for the part hosting the characteristic of interest. The objective is to reduce the latter to the smallest size necessary. If selection is applied for the desired characteristic only, then the proportion of donor genome is expected to be reduced by one-half (50%) at each generation, except on the chromosome holding the characteristic, on this chromosome, the rate of decrease is slower (Stam and Zeven, 1981; Naveira and Barbadilla, 1992).

In back cross have a donor parent (has a gene of interest) and a recurrent parent (an elite line that could be made better by adding the gene of interest). The donor parent is crossed to the recurrent parent. The progeny of this cross is then crossed to the recurrent parent (it is 'crossed back' to the recurrent parent, hence the term back cross). The progeny of this cross is selected for the trait of interest and then crossed back to the recurrent parent. This process normally is repeated for as many back crosses as are needed to create a line that is the recurrent parent with the gene of interest from the donor parent (Naveira and Barbadilla, 1992). The goal of backcrossing is to obtain a line as identical as possible to the recurrent parent with the addition of the gene of interest that has been added through breeding. Backcross breeding has been instrumental in achieving significant advancements in fruit crops across various traits. Some notable achievements include:

Disease resistance

Backcross breeding has been successful in introducing resistance to various diseases and pests in fruit crops. For example, in tomatoes, genes for resistance to diseases like tomato yellow leaf curl virus (TYLCV) and bacterial wilt have been introgressed into commercial cultivars through backcross breeding, leading to improved crop resilience and reduced yield losses.

Abiotic stress tolerance

Backcross breeding has been used to enhance tolerance to abiotic stresses such as drought, salinity, and extreme temperatures in fruit crops. Through the introgression of genes associated with stress tolerance, improved cultivars with enhanced resilience to adverse environmental conditions have been developed, contributing to increased yield stability and sustainability.

Improved fruit quality

Backcross breeding has played a crucial role in improving fruit quality traits such as taste, flavor, texture, color, and nutritional content. By selectively introgressing genes governing these traits from wild or exotic germplasm into elite cultivars, breeders have developed fruit varieties with superior sensory attributes and nutritional profiles, meeting consumer preferences and market demands.

Extended shelf life

Backcross breeding has been utilized to enhance the shelf life and post-harvest characteristics of fruit crops. Through the incorporation of genes associated with delayed ripening, reduced susceptibility to bruising, and enhanced storage capabilities, new cultivars with extended shelf life and improved marketability have been developed, benefitting both producers and consumers.

Adaptation to new environments

Backcross breeding has facilitated the adaptation of fruit crops to new or challenging growing environments. By introgressing genes for traits such as cold or heat tolerance, soil adaptability, and resistance to specific local pests and pathogens, breeders have expanded the cultivation range of fruit crops, opening up new production opportunities in diverse geographic regions.

Reduced chemical inputs

Backcross breeding has contributed to the development of fruit cultivars with inherent resistance to pests and diseases, thereby reducing the reliance on chemical pesticides and fungicides in crop production. This not only lowers production costs for growers but also promotes environmentally friendly and sustainable agricultural practices.

Overall, backcross breeding has been a powerful tool for fruit crop improvement, enabling breeders to strategically introgress desirable traits into elite cultivars while preserving their valuable agronomic attributes. These achievements have had a significant impact on enhancing productivity, quality, sustainability, and resilience in fruit crop production systems worldwide.

Challenges and future directions:

While precision breeding offers immense potential for fruit crop improvement, several challenges and opportunities warrant attention. These include regulatory constraints related to genome editing, intellectual property rights, and public acceptance of genetically modified organisms (GMOs). Additionally, the integration of multi-omics approaches, including genomics, transcriptomics, and metabolomics, could further enhance the efficiency and precision of breeding programs. Collaboration among academia, industry, and regulatory agencies is essential to foster innovation, address technological barriers, and promote the responsible deployment of precision breeding tools for sustainable fruit crop production.

Conclusion:

Precision breeding represents a paradigm shift in fruit crop improvement, offering unprecedented opportunities for targeted trait enhancement, accelerated breeding cycles, and sustainable agriculture. By leveraging molecular tools and genomic resources, breeders can address pressing challenges such as disease outbreaks, climate variability, and changing consumer preferences. However, realizing the full potential of precision breeding requires concerted efforts to overcome technical, regulatory, and socio-economic barriers. Through collaborative research, innovation, and stakeholder engagement, precision breeding can contribute to the development of resilient, nutritious, and high-yielding fruit crop varieties, ensuring food security and environmental sustainability in a rapidly changing world.

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SMART FARMING: AUTOMATION AND ROBOTICS IN AGRICULTURE

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Abstract:

The agriculture industry is faced with formidable obstacles because of the population's fast increase and rising food demand. "Smart farming" using automation and robotics seems like a game-changing option to handle issues in a sustainable manner. This introduction examines smart farming and provides evidence statistics and results of its significant influence on contemporary agriculture. The world population is predicted to reach 9.7 billion people by 2050, demanding higher food production, yet there are challenges due to the lack of arable land, water shortages, and climate change. Using technology, smart farming represents a paradigm change in agriculture. Labor-related issues, such as the lack of skilled farm employees because of rural-to-urban migration, reduce the productivity and profitability of conventional farming. By focusing on automation and robotics, smart farming addresses these issues by minimizing the need for human labour and optimizing operations. Due to intensive techniques that deplete the soil and increase greenhouse gas emissions, traditional agriculture suffers resource constraints as well as environmental problems. Contrarily, smart farming uses technology and data-driven precision agriculture to maximize resource utilization, reduce waste, and have a minimal negative impact on the environment. With AI-equipped autonomous tractors, harvesters, and robotic weeders, automation and robotics are transforming traditional farming, increasing production and efficiency while lowering reliance on human labour. By encouraging environmentally friendly methods and reducing chemical inputs to create healthier ecosystems and a smaller ecological imprint, smart farming is in line with environmental sustainability and climate resilience. This demonstrates how smart farming may help ensure a sustainable future for the industry.

Keywords: Smart Farming, Automation, Robotics, Agriculture Industry, Rising Food Demand, Sustainability.

Introduction:

The agriculture sector faces enormous problems because of the world population's fast growth and rising food consumption. The use of automation and robots in agriculture, sometimes known as "smart farming," has emerged as a game-changing option to handle these problems in a sustainable manner. This introduction goes into the subject of smart farming and is supported by statistics and outcomes that show how it has had a major influence on contemporary agriculture. By 2050, it is anticipated that there will be 9.7 billion people on the planet, which would need a significant increase in food production (De Wrachien *et al.*, 2021). To fulfil the growing demand for food, the Food and Agriculture Organization (FAO) estimates that agricultural output must increase by 50–60%. (Ashraf *et al.*, 2021). However, the amount of arable land that can be used for farming is constrained, there is a shortage of water, and there are problems brought on by climate change. In this context, "smart farming" has come to represent a paradigm-shifting strategy that uses technological developments to alter agriculture.

Concerns about a lack of workers and rising prices have intensified the agricultural sector. Traditional farming mainly relies on physical labour, but there aren't enough qualified farm labourers because of the ongoing movement of rural people to urban areas. As a result, farmers struggle to maintain production and profitability. With an emphasis on automation and robotics, smart farming aims to address these labor-related challenges by providing a solution that lessens reliance on human labour and simplifies agricultural processes (United States, Congress, 1984). Traditional agriculture has difficulties because of resource shortages and environmental concerns. Intensive agricultural methods, which are characterized by high use of water, chemical fertilizers, and pesticides, deplete the soil and increase greenhouse gas emissions. However, smart farming uses technology- and data-driven precision agriculture methods to maximize resource use. Farmers may deploy resources more effectively thanks to real-time data from cutting-edge sensors and satellite imaging, greatly lowering wastage and environmental impact (Paul *et al.*, 2022).

Automation and robots are becoming more and more common in agriculture as a result of the emergence of smart farming. Traditional farming activities have been changed by autonomous tractors, harvesters, and robotic weeders fitted with highly advanced AI algorithms (Gorjian *et al.*, 2020). These clever machines manoeuvre through the terrain, carry out precise tasks, and maximize output. Farmers benefit from increased operational effectiveness, decreased reliance on labour, and improved overall productivity, which has a positive effect on the agriculture industry. In contemporary agriculture, environmental sustainability and climatic resilience are also crucial factors. These objectives are in line with smart farming techniques, which encourage environmentally benign methods and environmental flexibility. Smart farming promotes healthier ecosystems and a smaller ecological imprint by limiting the need of chemical inputs, further highlighting its potential to support a sustainable future for agriculture.

Precision farming

Precision farming, also known as smart farming or precision agriculture, is a cutting-edge method of agricultural operations that makes use of cutting edge technology and data-driven strategies to maximize crop output while reducing resource loss (Bucci *et al.,* 2018). The constraints created by a constantly expanding global population, climate change, and the necessity for sustainable agricultural techniques have given rise to this novel farming technique. Precision farming is fundamentally dependent on a confluence of cutting-edge technology, including satellite imaging, GPS, drones, sensors, and machine learning algorithms (Qiao *et al.*, 2022). Figure 1. Shows the technologies involved in precision agriculture. With the use of these instruments, farmers are able to gather data in real-time on a variety of characteristics of their fields, such as the condition of the soil, moisture levels, crop development, and insect infestations. Farmers may increase production and efficiency by using this data to analyze when, where, and how to use certain resources.

The capacity of precision farming to maximize resource usage is one of its main advantages (Monteiro *et al.*, 2021). Precision farming enables customized application depending on the particular requirements of each crop and portion of the field, as opposed to evenly administering irrigation water, fertilizers, and pesticides over the whole field. This focused strategy reduces runoff and chemical leakage into adjacent water sources, which not only conserves important resources but also has a minimal negative impact on the environment. The use of autonomous machinery and GPS technologies has transformed the planting and harvesting procedures (Zambon *et al.*, 2019). Seeds are sown at the ideal depth and spacing thanks to the remarkable accuracy of GPS-guided tractors and other machinery. Yield monitoring devices enable farmers to evaluate the productivity of various fields during harvest, enabling them to modify procedures for the next growing seasons.

Furthermore, crop diseases, pests, and nutritional deficits may all be early identified thanks to precision farming. Modern sensors and drones may spot minor changes in crop health, allowing for prompt disease-prevention measures and pesticide usage optimization (Verma *et al.*, 2023). This benefits farmers as well as consumers by increasing food yields while reducing the use of dangerous pesticides. Precision farming is data driven, which implies that farmers may gain from data analytics and predictive modeling. Farmers may choose the optimum hybrids, crop rotation, and planting and harvesting periods by integrating real-time information with historical data analysis (Javaid *et al.*, 2023). As a result, risks are decreased and total profitability is increased.

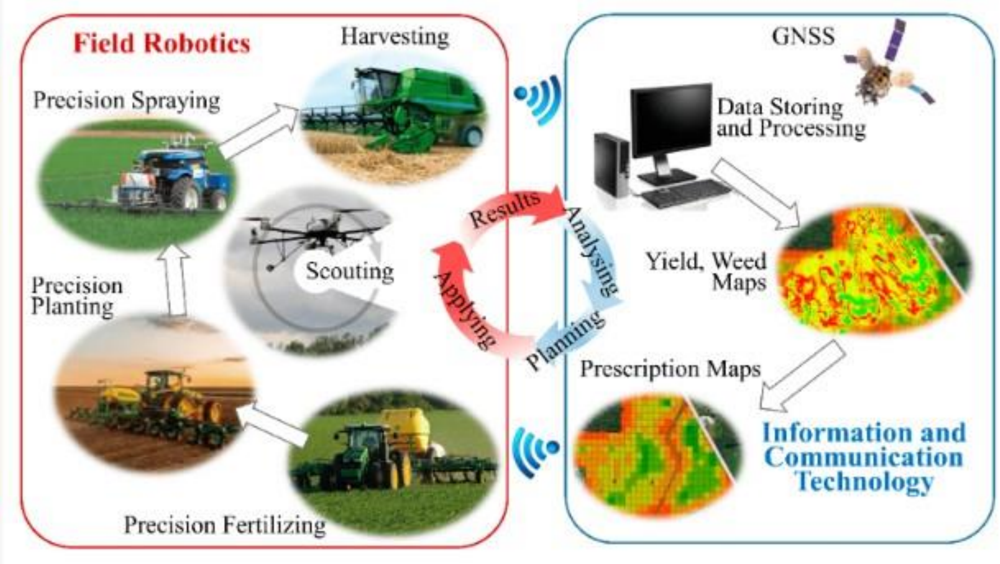

Fig. 1: Technologies involved in precision agriculture

Additionally, industrial-scale agriculture is not the only application of precision farming. Smaller farms and even urban farming, where space is at a premium, can use the same principles. For example, vertical farming and hydroponics may make use of precise environmental control to enhance crop output in constrained spaces. Precision farming has obstacles to widespread adoption despite its many benefits. For smaller farms, the initial setup expense and continuous technological expenses might be prohibitive. Understanding and utilizing the enormous amount of created data efficiently also involves a learning curve.

Precision farming collects, processes, and analyses data on crops, soil, and weather using cutting-edge technologies and data analytics. Farmers are better able to manage resources, become more productive, and have fewer environmental effects thanks to this data-driven strategy (Liang and Shah, 2023). Real-time monitoring of soil moisture, temperature, and crop health using sensors enables farmers to quickly address any problems. Additionally, data-driven insights help control pests, estimate the best times to sow and project yields, and maximize water use (Linaza *et al.*, 2021). Precision farming's data-driven methodology will be essential in determining the course of agriculture in the future and providing sustainable solutions to the world's food problems.

Tools and technologies

Drones

In areas like security and agriculture, drones have shown to be a beneficial complement to human existence. By offering imaging capabilities for activities like weed detection, fertilizer application, and real-time weather forecasting, these autonomous flying machines either pre-programmed or remotely controlled have changed agriculture (Pathak *et al.,* 2020). For these uses, autopilot drones with cameras and GPS are frequently employed. They are viewed as promising tools for farmers since they allow for the exact application of herbicides and fertilizers, which preserves the environment while also decreasing labour costs. Drones do, however, have significant drawbacks, such as pricy technology and a little carrying capacity for spraying (Hafeez *et al.,* 2022).

Drones in agriculture use sensors like accelerometers, gyroscopes, digital compasses, and barometers to determine their position and speed while in flight and to adjust. By using information from geostationary satellites, GPS sensors are essential for guiding drones over specific fields. Precision and accuracy are increased by fusing satellite data with other data. Additionally, drones can fly independently thanks to connected cameras and vision algorithms, which help with crop health monitoring and disease and weed detection in the agricultural sector (Delavarpour *et al.,* 2021).

Satellite imagery

In nations with huge farm sizes like the US and EU, satellite remote sensing is appealing for farm management since it allows high-resolution picture data collection across vast regions instantly. Commercial satellite remote sensing solutions in these areas, like FARMSTAR in France, have shown important advantages. Farmers that used this service saw a gain in revenue thanks to better yields, higher grain protein content, and less fertilizer use. However, due to spatial resolution and financial limitations, practical uses of satellite remote sensing have been restricted in most Asian nations, including Japan, where tiny fields are common (Inoue, 2020). But with high-resolution diagnostic data, the most recent satellite and information technologies might facilitate smart farming on a regional scale. Case studies in wheat and rice farming have shown the viability of applying information-based smart farming methods by effectively using satellite remote sensing to estimate canopy chlorophyll content, canopy nitrogen content, grain protein content, and optimal harvesting dates (Wan *et al.,* 2020). The evaluation of soil fertility may also be improved by using satellite sensors with more wavebands, which opens the door to better soil and fertilizer management over a wider variety of soil types and surface conditions.

Internet of Things (IoT)

In several industries, including agriculture, the Internet of Things (IoT) technology has changed the game. The Internet of Things has had a tremendous influence on efficiency and performance across several sectors by enabling remote connectivity and smart agricultural techniques. IoT applications for contemporary agriculture include cloud-based information analysis, mobile devices, smart objects, sensors, communication infrastructure, and automation of agricultural processes. Farmers can estimate production levels, evaluate weather, remotely monitor plants and animals, and properly manage water use. IoT technology makes it possible to manage nutritional deficits, pests, and illnesses, setting a new standard for contemporary agriculture (Dhanaraju *et al.*, 2022). The virtual devices in CPSs are connected via the Internet, while the real equipment is connected *via* the IoT.

The advancement of IoT technology has transformed agriculture, improving resource efficiency, temperature management, and agricultural yields. To monitor and transmit agricultural information at various growth phases, researchers suggest a variety of techniques and tools. Data collection and distribution methods include the use of communication tools, sensors, robots, drones, and other equipment. To safeguard the safety of food and the environment, government institutions are also involved in drafting rules and regulations for responsible technology usage. Consolidated data on conventional agricultural practices, strategies, tools, pests, and illnesses are made available through an accessible and interactive monitoring platform for sustainable agriculture. Strong models to address the sector's diversity and complexity, scalability to accommodate various farm sizes, affordability to support farming success, and sustainability to withstand economic pressures and international competition are important factors to consider when implementing IoT in agriculture (Luyckx and Reins, 2022).

“5G network” on smart farming

With wireless network technologies like 3G, 4G, and NB-IoT linking smart devices through the Internet of Things (IoT), the development of smart systems has witnessed tremendous advancements in communication and information technology. But as the amount and quality of information have increased, the 4G network's efficiency has decreased, leading to poorer data transfer. The advent of the fifth-generation communication network, or 5G, has been a game-changing innovation to get around these restrictions. With downlink rates of 10 Gbps and 20 Gbps and data transformation speeds that are over 100 times faster than those of 4G, 5G has emerged as an excellent choice for a variety of smart applications, including smart farming (Tang *et al.,* 2021).

With its high data transfer capacity, low latency, extremely high connection density, improved spectrum efficiency, streamlined communication performance, wide coverage, and high network energy efficiency, the 5G network has several benefits that may be used in smart applications. The 5G network has already been implemented by several nations, including the United States, Canada, certain European nations, Australia, China, and Japan. However, there is still a digital gap, with almost 80% of rural residents in the UK missing 4G connectivity, which makes it difficult to install cutting-edge smart technologies in rural regions. However, since 2017, 5G has been successfully applied to smart farming, revolutionizing processes like crop harvesting, fertilization, and the application of pesticides and seeds using drones and autonomous tractors (Ajmani and Saigal, 2023). By enabling effective drone control, real-time monitoring, seeding, pesticide and fertilizer spraying, as well as the use of AI-powered robots and data analytics in farming processes, this technology has significantly improved agricultural practices.

Data-driven management for advanced farming

Crop management in the past relied on eye examination and farmers' knowledge to make choices and treat crops appropriately. Field management has changed, though, with the rise of Precision Agriculture and the digital information age. In farms with cutting-edge technology, intelligent decision making is based on factual field data (Saiz-Rubio and Rovira-Más, 2020). This entails the use of sensors to gather precise measurements from the environment, the soil, and the crops. To make sure that the farmers only receive pertinent information, the gathered data is next analyzed using filtering procedures and AI algorithms. The growers then act in response to these insights using cutting-edge machinery that can be managed by computer systems. This process of gathering information, making decisions, and acting is repeated again until the crop is harvested. Agriculture has undergone a revolution because of the move toward objective data-driven crop management, which replaced subjective visual evaluations with a method that is more effective and exact. Technology and data analysis together provide for better knowledge and use of the crop's spatial and temporal variability. Crop yields, resource management, and overall agricultural output might all be considerably increased by this data-driven strategy.

Efficient resource utilization

Precision irrigation

In agriculture, precision irrigation is a cutting-edge water management strategy that makes use of sensors, data analytics, and automation to supply irrigation with efficiency and accuracy. To maximize water use and improve agricultural yield, it considers elements such as soil moisture levels, weather patterns, crop type, growth stage, and terrain. Farmers can precisely determine the amount of water their crops need by placing sensors around the field to track soil moisture and other environmental factors in real time. To prevent water waste or an insufficient supply, these data are then utilized in complex computer algorithms to determine the ideal amount and time of irrigation. Integration of automation enables remote management and control of irrigation, increasing efficiency and requiring less personnel (Masseroni *et al.,* 2018).

Precision irrigation (Figure 2), a data-driven and technologically focused strategy, is transforming agriculture by assisting farmers in coping with climate change, water resource conservation, and sustainable productivity growth.

Fig. 2: Precision Irrigation

Nearly half of the world's population will experience escalating water scarcity by 2030, according to the UN Convention to Combat Desertification (UNCCD), which also warns about the probable desertification of 168 countries. It is essential to implement more regulated and effective irrigation techniques, such as drip and sprinkler irrigation, to preserve water in response to these water problems and the rising need for agriculture. Wireless sensor-equipped air and soil moisture control systems allow for the most efficient use of water and better crop health. IoT methods, especially CWSI-based water management, have the potential to greatly boost crop output (Chen *et al.*, 2020). The CWSI model calculates water requirements using climate data, sensor information, and satellite imagery, enabling farmers to make educated decisions and increase the efficiency of water use for specific areas.

Targeted fertilization

A cutting-edge agricultural technique called targeted fertilization, commonly referred to as precision fertilization, optimizes fertilizer administration depending on the requirements of individual plants or field regions. This strategy makes use of cutting-edge technology like soil sensors, satellite images, and data analytics to spot fluctuations in soil nitrogen levels, crop health, and other elements that affect the need for fertilizer. Farmers may minimize waste and its impact on the environment while increasing crop yields by customizing fertilizer application rates and timing. Farmers gather information about their fields, such as soil nutrient levels, crop varieties, development phases, and historical production statistics, to perform targeted fertilization. Precision fertilization, another name for targeted fertilization, is a cutting-edge agricultural technique that optimizes fertilizer administration depending on the requirements of individual plants or field sections. To detect fluctuations in soil nutrient levels, crop health, and other factors that affect fertilizer requirements, this strategy makes use of cutting-edge technology including soil sensors, satellite images, and data analytics. Farmers may minimize waste and its impact on the environment while optimizing crop yields by customizing the rates and timing of fertilizer application. Farmers gather information about their fields, such as the sorts of crops grown there, their growth phases, and previous production statistics, to perform targeted fertilization.

Controlled Environment Agriculture (CEA)

Controlled Environment Agriculture (CEA) is a cutting-edge agricultural method that generates artificial settings for crops to be grown in with exact control over environmental elements including temperature, humidity, light, and CO_2 levels. Its main objective is to maximize agricultural conditions, regardless of changes in the outside weather, to increase yield and quality. This approach is especially helpful if there is a lack of arable land or a difficult environment. CEA employs enclosed facilities with advanced technology and automated systems, such as greenhouses, vertical farms, or indoor settings (R Shamshiri *et al.,* 2018). To establish the optimal growing environment for each crop, farmers may control variables like temperature, humidity, irrigation, and light. This results in faster crop growth rates, less water use, and a decreased need for pesticides. A sustainable and resilient approach to modern agriculture, CEA permits year-round production, maintaining a consistent supply of fresh products and reducing crop losses due to pests and harsh weather.

Minimizing waste and environmental impact

By maximizing resource utilization and placing inputs exactly where they are quired, the sophisticated agricultural practice known as "precision farming" seeks to reduce waste and its negative effects on the environment (Perakis *et al.*, 2020). This ground-breaking method uses technology, data analytics, and automation to make smart crop management decisions, leading to more effective and sustainable agricultural methods. Real-time information on the farm's circumstances, such as soil health, moisture levels, crop development, and insect infestations, is gathered using a variety of technologies, including GPS, remote sensing, drones, and sensors. Farmers may construct accurate and site-specific management plans for their crops by combining this data with powerful computer algorithms. For instance, they may use insecticides and fertilizers only where they are truly necessary, avoiding unnecessary use and lowering the chance of contamination. Like how soil moisture levels and weather predictions may be used to manage irrigation, prevent overwatering and preserve water resources. This deliberate strategy improves resource efficiency while minimizing the environmental damage caused by excessive chemical usage, water runoff, and greenhouse gas emissions from conventional agricultural methods. Additionally, precision farming enables farmers to implement conservation strategies like cover crops and less tillage, improving soil quality and reducing erosion (Saleem *et al.*, 2023). Overall, precision farming is a huge step toward sustainable agriculture, encouraging prudent resource management and easing the environmental burdens that contemporary agriculture must bear.

Automated machinery

Autonomous tractors, harvesters, and weeders

Fig. 3: Autonomous tractors

Modern agricultural gear, such as autonomous tractors, harvesters, and weeders, may function without direct human involvement (Narasimman *et al.,* 2022). These autonomous robots can carry out a variety of activities in the field with great accuracy and efficiency since they are outfitted with cutting-edge technology like GPS, sensors, cameras, and artificial intelligence. With the help of GPS and sophisticated navigation systems, autonomous tractors (Figure 3) perform as self-driving vehicles and handle cultivating, sowing, and ploughing while assuring proper seed and fertilizer distribution (Addicott and Addicott, 2020). Based on real-time sensor data, they may modify their speed and course, maximizing fuel efficiency and minimizing soil compaction. Farmers may reduce time, labour, and operating expenses while boosting output by automating these processes.

Similar to human harvesters, autonomous harvesters carry out harvesting tasks like selecting fruits or gathering grains on their own. They recognize ripe crops and carry out precision harvesting using cameras and sensors, reducing waste and assuring high-quality products. With continuous harvesting possible even in bad weather or long hours thanks to this autonomous operation, yields are increased and post-harvest losses are decreased. Additionally, autonomous weeders can find and eliminate weeds from fields without endangering the crops by using computer vision and machine learning algorithms (Pandey *et al.,* 2021). The use of pesticides and physical labour is decreased due to the ability to remove weeds with pinpoint accuracy, encouraging sustainable and environmentally friendly weed control techniques. With the ability to increase productivity, reduce environmental impact, and provide farmers with cutting-edge tools to optimize their operations, these ground-breaking devices have the potential to completely transform modern agriculture.

Advanced sensors, GPS and AI algorithms

The agriculture business has been transformed by disruptive technology such as advanced sensors, GPS, and AI algorithms that allow farmers to make data-driven choices and optimize their operations with unheard-of accuracy (Patel *et al.,* 2023). Together, these technologies gather, process, and analyze enormous volumes of data, enabling farmers to better manage their resources, increase output, and have less negative impact on the environment. Intelligent choices on irrigation, fertilization, and pest management are made possible by the constant monitoring of several factors by advanced sensors in the field. These sensors provide real-time data on soil moisture, temperature, nutrient levels, and plant health. Precision mapping and spatial data processing are made possible by GPS technology (Figure 4), allowing for exact machine navigation and site-specific management techniques. Additionally, AI systems analyze sensor and GPS data to find trends, forecast the best times to plant, crop yields, and spot agricultural illnesses and pests early on. AI-powered farm management solutions increase productivity, decrease human error, and promote more sustainable and effective agriculture by automating processes and offering insightful data (Javaid *et al.*, 2023). Agriculture is moving toward a data driven future because of the incorporation of cutting-edge sensors, GPS, and AI algorithms. This will enable farmers to traverse the complexity of modern farming with better sustainability and precision.

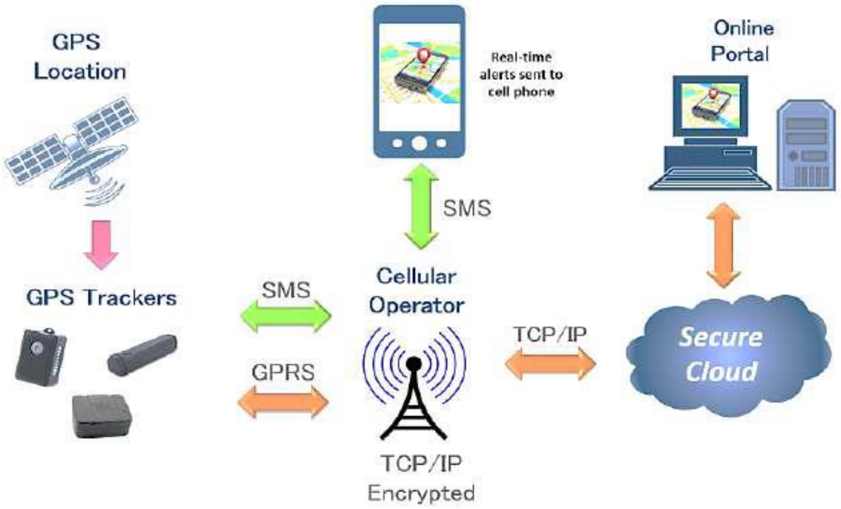

Fig. 4: Explanation of GPS Technology

Benefits of automation in reducing labor costs and increasing productivity

Numerous advantages of automation in agriculture include lower labour costs and higher output. Advanced machines and robots using technology like sensors, GPS, and AI can complete labor-intensive jobs quickly and accurately, with less human involvement. Since inputs like water and fertilizers are supplied precisely where and when they are needed, eliminating waste and environmental effects, this results in continuous field operations and enhanced resource management. Agricultural techniques are further optimized by data-driven decision making using sensor data and AI algorithms, enabling farmers to adapt to changing conditions, enhance production, and implement sustainable and lucrative farming practices (Linaza *et al.*, 2021). The incorporation of intelligent farm management systems enables coordinated operations amongst multiple pieces of equipment, increasing efficiency and yielding further labour cost reductions. In general, the use of automation equips farmers with the knowledge they need to make wise decisions, increase production, and turn agriculture into a data-driven and effective enterprise.

Crop monitoring and management

Modern agriculture has been transformed by crop monitoring and management using real-time sensor and camera technologies, which have given farmers invaluable knowledge and tools to maximize crop growth and output (Paul *et al.*, 2022). Farmers can precisely manage irrigation and guarantee effective water consumption by deploying cutting-edge sensors and cameras to closely monitor critical factors including soil moisture, temperature, and crop health. This encourages healthier and more robust crops. Temperature sensors also enable farmers to react quickly to bad weather, protecting crops from frost or heat waves. Additionally, computer vision technology-enabled cameras make crop health monitoring possible, enabling early diagnosis of illnesses, pests, or nutritional deficits, resulting in prompt treatments and protected crop output. By processing massive quantities of data from sensors and cameras, identifying trends, and identifying possible crop concerns before they become obvious, the incorporation of artificial intelligence (AI) adds greater sophistication. The AI-driven analysis enables farmers to make data-driven decisions, maximizing crop management by modifying irrigation schedules, fine-tuning fertilizer treatments, and applying pesticides only when necessary, saving costs and having the least negative impact on the environment. Real-time crop monitoring combined with AI-driven analysis has several benefits, enabling farmers to improve crop health, boost yields, and achieve more sustainable and effective resource usage, changing conventional agricultural techniques into modern, sustainable agriculture.

Greenhouse automation

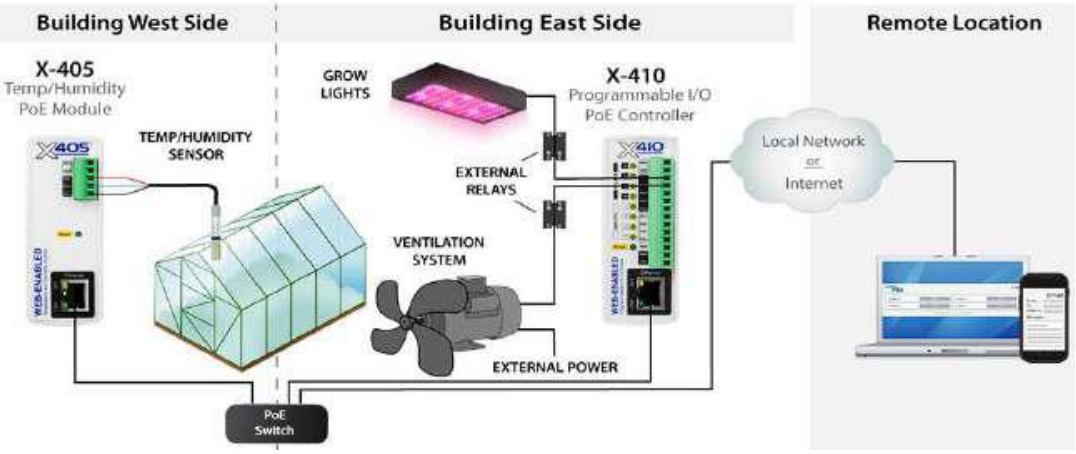

Fig. 5: Smart Greenhouse Automation

Modern agriculture has undergone a paradigm shift with greenhouse automation, which improves resource management, increases crop output, and optimizes operations. Advanced technology, including robots and automated climate control systems, is used to handle many parts of greenhouses. By monitoring temperature, humidity, CO_2 levels, and ventilation, avoiding manual intervention, and conserving energy, automated climate management maintains the best conditions. Precision automation using robotics increases productivity and lowers labour costs by automating activities like planting, trimming, and harvesting. Through real-time data-driven choices on the use of water and nutrients, greenhouse automation also enhances resource management, fostering sustainability and high-quality crop yields (Liang and Shah, 2023). With the help of this innovative technology, greenhouse farming is transformed, becoming more effective, commercially feasible, and crucial to sustainable agriculture and global food security. Figure 5. presents information about the automated smart greenhouse.

Livestock management

Numerous advantages have resulted from the introduction of automation in livestock management for the agriculture sector. Automated feeding systems guarantee precise and constant food delivery, boosting good nutrition and minimizing waste. Farmers may meet the demands of individual animals using this method, increasing output overall and reducing time and labour requirements. Additionally, the use of wearables and sensors allows for real-time animal health and behavior monitoring, allowing early illness identification and prompt intervention (Neethirajan, 2017). Higher growth rates and increased reproductive efficiency are the results of the data-driven strategy, which guarantees proactive care and enhances animal well-being. Continuous monitoring made possible by automation helps farmers to respond quickly to emergencies and maximize resource use. Generally, automation is transforming the livestock management sector and improving sustainability, productivity, and animal welfare.

Challenges and adoption

With its cutting-edge technology, smart farming has the potential to completely alter the agricultural industry, but it also comes with several difficulties that must be overcome before it can be widely adopted. One significant barrier is the hefty upfront expenses, which might discourage small-scale and developing region farmers. It can be costly to adopt and maintain advanced technology like automation systems, drones, sensors, and GPS. Due to the vast volumes of private data that smart farming collects and analyses, data security is also essential (Gupta *et al.,* 2020). Strong data protection policies and standards are required because farmers must make sure that their data is shielded from illegal access and breaches.

Another difficulty is that, especially for elderly and rural farmers, using smart agricultural technologies efficiently requires specific training and knowledge. To provide farmers with the knowledge and abilities to use and maintain these cutting-edge devices, appropriate training programs are essential. Governments and agricultural organizations, particularly for smaller farms, play a critical role in promoting the use of smart farming through financial incentives, subsidies, and grants (Tankha *et al.,* 2020). Collaboration is also crucial in the creation of cost-effective solutions and information exchange. The agricultural industry may use the promise of smart farming for a more sustainable, effective, and productive future by proactively addressing these issues.

Conclusion:

With the use of cutting-edge technology like sensors, drones, GPS, and AI, smart farming has a significant chance of supplying the world's food needs sustainably. It increases production, lowers environmental impact, and optimizes resource use. By offering precise control and real-time data, smart farming enhances resource management while optimizing the use of pesticides, fertilizers, and water. This encourages the adoption of sustainable agricultural techniques. Additionally, AI-driven analysis increases production by providing data-driven decisions for the best planting, pest management, and harvesting. Smart farming encourages soil health, biodiversity, and the averting of climate change by lowering reliance on traditional methods and putting conservation techniques into practice. Smart farming is positioned as a crucial answer in assuring a robust and sustainable food supply for the future, with the prospect of additional technical breakthroughs.

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PRECISION AGRICULTURE: REVOLUTIONIZING FARM MANAGEMENT

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Introduction:

Precision agriculture, also known as site-specific crop management or precision farming, represents a paradigm shift in agricultural practices, leveraging advanced technologies to enhance productivity, sustainability, and profitability. This innovative approach integrates information technology with agronomic practices to manage variations in the field, optimize inputs, and reduce environmental impact (Gebbers & Adamchuk, 2010). By utilizing tools such as GPS, remote sensing, and IoT devices, precision agriculture enables farmers to make data-driven decisions, tailoring interventions to the specific needs of crops and soil at a micro-level. The origins of precision agriculture can be traced back to the adoption of GPS technology in the 1980s, which provided farmers with the capability to map fields with high precision. This technological foundation laid the groundwork for the development of variable rate technology (VRT), allowing the precise application of inputs like fertilizers and pesticides based on field variability (Pierce & Nowak, 1999). Over the past few decades, the field has evolved dramatically, incorporating advancements in sensors, data analytics, and machine learning, transforming traditional farming into a highly sophisticated, data-centric enterprise.

One of the key benefits of precision agriculture is its potential to enhance resource use efficiency. For instance, precision irrigation systems can significantly reduce water usage by delivering the right amount of water at the right time and place, addressing the growing concerns over water scarcity in agriculture (Sadler *et al.*, 2005). Similarly, precision nutrient management ensures that crops receive optimal nutrition, reducing the risk of over-application and subsequent environmental degradation (Bongiovanni & Lowenberg-DeBoer, 2004). Moreover, precision agriculture plays a crucial role in promoting sustainable farming practices. By minimizing the overuse of agrochemicals and optimizing resource inputs, precision agriculture contributes to the reduction of greenhouse gas emissions and the preservation of biodiversity. This approach aligns with global efforts to mitigate climate change and promote environmentally friendly farming practices (Gebbers & Adamchuk, 2010). The adoption of precision agriculture is not without challenges. High initial costs, the need for technical expertise, and the integration of diverse technologies can pose significant barriers to widespread implementation, particularly for small-scale farmers. However, ongoing research and development, along with supportive policies and training programs, are paving the way for broader accessibility and adoption of precision agriculture technologies (Zhang *et al.,* 2002).

In summary, precision agriculture represents a transformative approach to farm management, harnessing the power of advanced technologies to enhance efficiency, sustainability, and profitability. As the agricultural sector faces increasing pressures to produce more with less, precision agriculture offers a viable solution to meet these demands, ensuring the long-term viability of farming practices.

Historical background

Precision agriculture, also known as precision farming, emerged as a concept in the late 20th century, driven by advancements in technology and a growing need for more efficient and sustainable farming practices. The historical roots of precision agriculture can be traced back to the integration of geographic information systems (GIS), global positioning systems (GPS), and remote sensing technologies in agricultural operations. The initial application of GPS technology in agriculture began in the 1980s, primarily for the purpose of mapping fields and monitoring crop yields. One of the pioneering efforts in this domain was the development of yield mapping systems, which allowed farmers to collect and analyse data on crop yields across different parts of their fields. This innovation marked a significant shift from traditional farming methods to more data-driven approaches.

In the 1990s, the concept of site-specific crop management (SSCM) gained traction, emphasizing the need to manage agricultural inputs such as fertilizers, pesticides, and water based on the specific conditions of different field zones. This period saw the introduction of variable rate technology (VRT), which enabled the precise application of inputs according to the spatial variability within fields. The evolution of precision agriculture was further accelerated by advancements in remote sensing technologies, including the use of satellites and drones to capture high-resolution imagery of crops. These technologies provided farmers with valuable insights into crop health, soil conditions, and pest infestations, allowing for more informed decision-making and timely interventions. In the early 21st century, the advent of big data analytics and machine learning revolutionized precision agriculture. These technologies facilitated the processing and analysis of large volumes of data collected from various sources, including sensors, weather stations, and farm equipment. The integration of these data analytics tools enabled farmers to optimize their operations, enhance productivity, and reduce environmental impact.

Today, precision agriculture continues to evolve with the incorporation of cutting-edge technologies such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain. These innovations are paving the way for a more connected and automated agricultural ecosystem, where real-time data and predictive analytics drive decision-making and resource management.

Core principles of precision agriculture:

I. Site-Specific Crop Management (SSCM): Tailoring crop management practices to specific field conditions.
II. Variable Rate Technology (VRT): Using data to apply inputs like fertilizers and pesticides at variable rates across a field.
III. Decision Support Systems (DSS): Utilizing data analysis and modelling to support farming decisions.

I. Site-Specific Crop Management (SSCM): Site-Specific Crop Management (SSCM) involves tailoring crop management practices to the unique conditions of different areas within a field. This principle recognizes that variability in soil properties, microclimate, pest pressures, and other factors can significantly impact crop performance. By using technologies like GPS mapping, soil sampling, and remote sensing, farmers can identify these variations and apply specific management practices—such as seeding rates, irrigation, and nutrient applications—precisely where they are needed. This approach enhances resource use efficiency and can lead to improved crop yields and reduced environmental impact (Bongiovanni & Lowenberg-Deboer, 2004).

II. Variable Rate Technology (VRT): Variable Rate Technology (VRT) is a core component of precision agriculture that allows the application of inputs such as fertilizers, pesticides, and seeds at varying rates across a field, based on the specific requirements of different zones. VRT systems rely on data collected from soil tests, yield maps, and other sensors to determine the optimal number of inputs needed for each area. By applying the right number of inputs precisely where they are needed, VRT helps to minimize waste, reduce costs, and decrease the environmental footprint of farming practices (Pierce & Nowak, 1999).

III. Decision Support Systems (DSS): Decision Support Systems (DSS) in precision agriculture use data analysis and modelling to help farmers make informed decisions about their farming operations. These systems integrate data from various sources, including weather forecasts, soil moisture levels, and crop health indicators, to provide actionable insights. DSS can offer recommendations on optimal planting times, irrigation schedules, pest management strategies, and more. By leveraging advanced analytics and modelling techniques, DSS can enhance decision-making processes, leading to more efficient and sustainable agricultural practices (McBratney, Whelan, & Ancev, 2005).

Key technologies in precision agriculture:

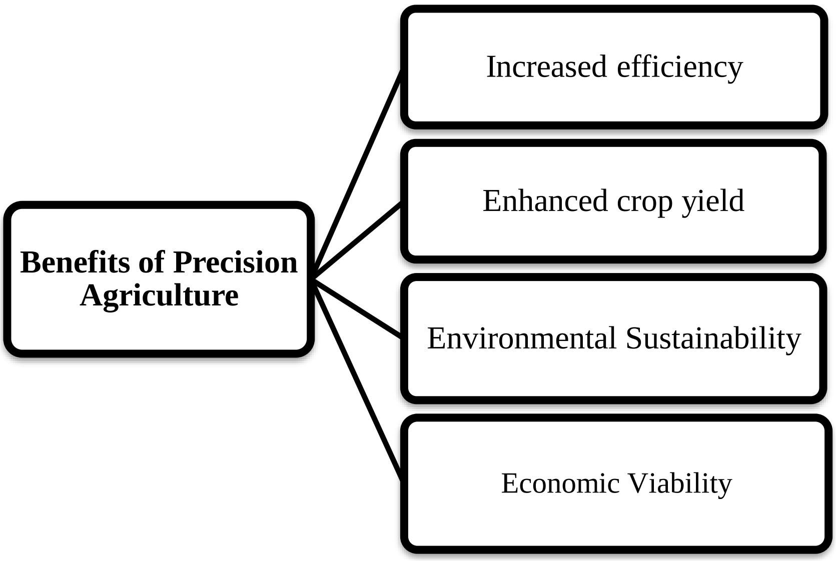
- Global Positioning System (GPS): GPS technology is essential for precision agriculture as it allows for accurate field mapping and navigation. By using GPS, farmers can precisely apply inputs like seeds, fertilizers, and pesticides, reducing waste and improving efficiency (Zhang *et al.*, 2002).
- Geographic Information Systems (GIS): GIS integrates various types of spatial data, enabling farmers to analyse and manage information related to soil, crop performance, and

environmental conditions. This integration helps in making informed decisions to optimize crop production (Whelan & McBratney, 2003).

- Remote Sensing: Remote sensing involves using aerial or satellite imagery to monitor crop health, soil conditions, and other critical factors. This technology allows for the early detection of stress factors like pests, diseases, and nutrient deficiencies, facilitating timely interventions (Mulla, 2013).
- Yield Monitors: Yield monitors are devices attached to harvesters that collect real-time data on crop yield and quality. This information helps farmers understand field variability and make data-driven decisions for future planting and input application (Arslan & Colvin, 2002).
- Soil Sensors: Soil sensors measure properties such as moisture, temperature, and nutrient levels. By providing real-time soil data, these sensors enable farmers to optimize irrigation and fertilization practices, improving crop growth and resource use efficiency (Sudduth *et al.,* 1997).
- Drones: Drones offer high-resolution aerial imagery for crop monitoring and management. They can quickly survey large areas, providing detailed information on plant health, growth patterns, and potential problem areas (Zhang & Kovacs, 2012).
- Autonomous Machinery: Autonomous machinery includes self-driving tractors and equipment for planting, spraying, and harvesting. These machines increase efficiency and reduce labour costs while ensuring precise and consistent field operations (Sørensen *et al.,* 2010).

Benefits of precision agriculture:

1. Increased Efficiency: Precision agriculture optimizes input use such as water, fertilizers, and pesticides, reducing waste and costs. This leads to more efficient resource utilization and ultimately higher profitability for farmers (Gebbers & Adamchuk, 2010).
2. Enhanced Crop Yields: By making data-driven decisions based on real-time information gathered from sensors, drones, and satellite imagery, precision agriculture helps farmers optimize planting, irrigation, and crop management practices. This leads to improved crop performance and higher yields (Slafer *et al.,* 2014).
3. Environmental Sustainability: Precision agriculture practices like variable rate application of inputs and targeted pest management reduce chemical runoff into water bodies and minimize soil erosion. This contributes to environmental sustainability by preserving water quality and soil health (Huang *et al.,* 2021).
4. Economic Viability: The increased efficiency and enhanced crop yields resulting from precision agriculture translate into better economic returns for farmers. This not only improves their financial stability but also supports long-term sustainability in agriculture (Basso *et al.,* 2019).



Implementation of precision agriculture:

Implementation of Precision Agriculture involves several key steps:

1. Data Collection and Analysis: Precision Agriculture relies heavily on data collection from various sources such as sensors, satellites, drones, and field equipment. This data includes information on soil moisture, nutrient levels, crop health, weather conditions, and more. Advanced software and algorithms are then used to analyze and interpret this data, providing valuable insights for decision-making. For example, data collected from sensors can help farmers monitor soil conditions in real-time, enabling precise irrigation and fertilization strategies (Assefa, A., Srinivasan, R., & Alagarswamy, G., 2019).
2. Equipment Integration: Implementing Precision Agriculture often requires integrating new technology into existing farming equipment or investing in specialized equipment designed for PA. This includes GPS-guided tractors, variable rate technology (VRT) for applying inputs like seeds and fertilizers based on specific field conditions, and drones for aerial imagery and monitoring. Integrating these technologies allows for more efficient and targeted farming practices, optimizing resource use and increasing productivity (Hoffmann, C. M., & Tekin, Y., 2021).
3. Farmer Education and Training: Successful adoption of Precision Agriculture requires educating and training farmers on how to effectively use PA technologies. This includes understanding how to collect and interpret data, operate specialized equipment, and implement data-driven management practices. Training programs, workshops, and access to educational resources play a crucial role in empowering farmers to leverage the full potential of Precision Agriculture for sustainable and profitable farming (Gupta, R., Shah, S. M., & Meena, M. L., 2020).

Challenges and limitations:

Challenges and limitations of precision farming are crucial aspects that impact its widespread adoption and effectiveness. Here's an elaboration on these challenges along with potential future prospects:

1. High Initial Costs: The adoption of precision farming involves significant initial investment in specialized equipment such as GPS-enabled machinery, sensors, drones, and data management software. This can be a barrier for small-scale farmers or those with limited capital resources (Hart, 2020).
2. Data Management: Precision farming generates vast amounts of data from various sources like sensors, satellites, and machinery. Managing and analyzing this data requires robust infrastructure and expertise in data analytics. Farmers may struggle with data integration, storage, and interpretation, leading to challenges in deriving actionable insights (Osgood *et al.,* 2018).
3. Technical Expertise: Effective implementation of precision agriculture techniques demands a high level of technical knowledge and skills. Farmers need training not only in operating advanced equipment but also in interpreting data outputs and making informed decisions based on them (Zhang *et al.,* 2021).
4. Infrastructure: Access to reliable internet connectivity and technological infrastructure is crucial for the seamless functioning of precision farming systems. In rural areas or regions with limited connectivity, farmers may face challenges in real-time data transmission and remote monitoring of agricultural operations (Du *et al.,* 2019).

Future prospects for precision farming include:

1. Artificial Intelligence (AI) and Machine Learning (ML): These technologies can enhance data analysis capabilities, enabling predictive modelling, yield forecasting, and optimized resource allocation in agriculture (Srivastava *et al.,* 2020).
2. Internet of Things (IoT): Integration of IoT devices allows for real-time monitoring of soil conditions, crop health, and equipment performance. This interconnected network improves data accuracy and enables automated decision-making in farming practices (Jha *et al.,* 2021).
3. Robotics: Advancements in robotics enable autonomous operations such as precision planting, spraying, and harvesting. This reduces labor dependency, increases operational efficiency, and minimizes resource wastage (Wang *et al.,* 2020).
4. Sustainable Practices: Precision farming can be integrated with sustainable agricultural practices such as conservation tillage, organic farming, and water management strategies. This integration promotes environmental sustainability, addresses food security challenges, and reduces the ecological footprint of farming operations (Liu *et al.,* 2021).

Conclusion:

Precision agriculture represents a transformative approach to farm management, leveraging advanced technologies to optimize agricultural practices. This methodical approach to farming, which includes using data-driven insights and state-of-the-art tools such as GPS, remote sensing, and IoT devices, has ushered in a new era of efficiency and sustainability. The historical journey of precision agriculture reflects the evolution from traditional methods to innovative, technology-driven strategies that focus on precision and accuracy. By understanding and applying the core principles of precision agriculture, farmers can tailor their practices to the specific needs of their crops and soil, thus maximizing productivity while minimizing resource use and environmental impact.

Key technologies in precision agriculture, such as variable rate technology, automated machinery, and drones, have become indispensable in modern farming. These tools enable precise application of inputs, accurate monitoring of crop health, and efficient management of farm operations. The benefits are manifold, including increased crop yields, reduced input costs, enhanced environmental stewardship, and improved overall farm profitability. Implementing precision agriculture, however, comes with its set of challenges and limitations. High initial costs, the need for technical expertise, and issues related to data management and integration are significant barriers. Additionally, smallholder farmers in developing regions may face difficulties in accessing and adopting these technologies due to financial constraints and lack of infrastructure. Despite these challenges, the future prospects of precision agriculture are promising. Ongoing advancements in technology, combined with increasing awareness and adoption, are expected to drive the widespread implementation of precision agriculture practices. Innovations such as artificial intelligence, machine learning, and big data analytics will further enhance the capabilities of precision farming, leading to more resilient and sustainable agricultural systems.

In conclusion, precision agriculture stands at the forefront of modern farming, offering solutions that align with the goals of sustainable development and food security. By continuing to innovate and address the challenges, precision agriculture has the potential to revolutionize farm management, ensuring that agriculture can meet the demands of a growing global population while preserving the planet for future generations.

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SPEED BREEDING AND ITS IMPICATION FOR CROP IMPROVEMENT

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Abstract:

Speed breeding technique is deemed as the future of plant breeding. Crop improvement in the face of a fast-changing environment and an ever-increasing human population is a major concern for scientists around the world. Speed breeding refers to a quick generation advancement technology used for decreasing the time of seed to seed cycle, thereby shortening the otherwise traditionally long life cycle of a crop plant. With the use of this technology, up to 6 generations per year for photo insensitive crops and 2-3 generations per year for other crops have been obtained. This method manipulates the photoperiodic conditions and temperature requirements of crops grown in controlled polyhouses. This method can accelerate crop breeding programmes and in use with other modern technologies like genome editing and high throughput genotyping platforms this technique can serve to breed new varieties at a much faster rate. This idea was originally conceptualized by National Aeronautics and Space Administration (NASA) in order to grow food at a faster pace in space. Whether speed breeding can be applied to a particular crop or not can be checked by the help of Breeder's equation. The core recipe of speed breeding involves manipulation of light, photoperiodic regime, temperature and humidity. This method has many applications like accelerated breeding, speeding up the process of genomic selection, boosting transgenic and CRISPR pipelines and to study physiological traits of important crop plants. Overall, the future of speed breeding is closely tied to advancements in science and technology, and it will continue to be a key driver of innovation in agriculture. This method has the potential to address the evolving challenges facing the agricultural sector, from climate change and population growth to the need for sustainable, resource-efficient and resilient crop production.

Keywords: Generation Advancement, Photoperiodic Conditions, Photo Insensitive, Speed Breeding.

SPEED

Introduction:

The growing human population and a changing environment have raised significant concern for global food security, with the current improvement rate of several important crops inadequate to meet future demand. Rapid climate change and the emergence of new pests and diseases threaten agricultural production. In conventional plant breeding, after making crosses between desired parents, selection and screening for the desired traits along with generation advancement of the selected material is time consuming and thus 8-10 years are required for development of new variety. This slow improvement rate is attributed partly to the long generation times of crop plants. To increase productivity and stability of crops to meet the changing climatic conditions, there is need to fast-track research and also increase the rate of cultivar development. This major problem can be conveniently overcome by use of speed breeding which involves quickening the breeding cycle from seed to seed by manipulating the photoperiodic conditions along with environmental conditions like soil media composition, temperature, spacing in the glass houses, all done to achieve rapid generation advancement.

Speed breeding is a technique used in plant breeding to accelerate the development of new crop varieties. It involves manipulating the growth conditions of plants, typically by controlling factors like light, temperature, and carbon dioxide levels, to promote rapid growth and shortening the breeding cycle. This approach has significant implications for crop improvement, including:

Faster variety development: Speed breeding can reduce the time it takes to develop new crop varieties, allowing breeders to respond more quickly to changing environmental conditions, emerging pests and diseases, and evolving consumer preferences. Traditional breeding methods can take years or even decades, while speed breeding can significantly shorten this timeframe.

Increased genetic diversity: By accelerating the breeding process, speed breeding allows forthe evaluation of a wider range of genetic material, which can lead to the discovery of new traits and genetic combinations that are beneficial for crop improvement. This can help developcrops that are more resistant to diseases, pests, and environmental stressors.

Crop adaptation to climate change: Speed breeding can help in the development of crop varieties that are better adapted to changing climate conditions. Rapid breeding cycles enable breeders to select for traits such as heat and drought tolerance more quickly, which is crucial as climate change continues to impact agriculture.

Enhanced yield and quality: Speed breeding can result in crop varieties with improved yieldand quality. The technique allows for the selection of plants that exhibit desirable traits, such as higher productivity, better taste and improved nutritional content.

Reduction in resource requirements: Speed breeding can reduce the amount of resources, such as land and water, required for traditional breeding programs. By growing plants in controlled environments, breeders can maximize the use of space and resources, making the process more efficient and sustainable.

Rapid response to emerging challenges: In the face of new diseases, pests or market demands, speed breeding can be instrumental in quickly developing crop varieties that address these challenges. This agility can help ensure food security and economic stability in agricultural communities.

Improved genetic mapping and understanding: Speed breeding can facilitate the rapid generation of plant populations for genetic studies. This helps scientists and breeders better understand the genetic basis of traits, which can lead to more precise breeding efforts.

Commercial benefits: Faster development of new crop varieties can benefit the agricultural industry by increasing the availability of improved cultivars and potentially increasing profitability for breeders, farmers, and agribusinesses.

However, it's important to note that speed breeding also comes with some challenges and concerns, including the need for careful monitoring of potential unintended consequences,as well as addressing ethical and safety issues related to genetically modified crops. Additionally, the extent to which speed breeding can be applied effectively varies between different crop species.

Overall, speed breeding has the potential to revolutionize crop improvement and help address the challenges of feeding a growing global population in the face of changing environmental conditions.

Speed breeding is such a tool or technique for rapid generation advance that significantly reduces the harvest time of crops in order to speed up agricultural research and increase the production of food to meet the demand of the growing population (Sankar *et al.,* 2020). The method saves breeding time and resources through rapid generation advancement. Various selection methods can be integrated into speed breeding, such as the single seed descent (SSD), single pod descent (SPD), single plant selection (SPS), clonal selection and marker assisted selection (MAS) to shorten the breeding cycle and for efficient resource use (Hickey *et al.,* 2017, Watson *et al.,* 2018).

In speed breeding, plants are grown in controlled environments with continuous light for 22 hours per day at optimal temperature. Many crops such as *Brassica* species, bread wheat, durum wheat, barley, chickpea, pea, grass pea, quinoa, oat and peanut at least four generations have been achieved in a single year using speed breeding (O'Connor *et al.,* 2013, Ghosh *et al.,* 2018, Watson *et al.,* 2018). This technology uses some artificial conditions to grow a crop under modified temperature, humidity, photoperiod time can be done in glass house conditions. The speed breeding technology along with these artificial conditions reduces the crop generation time much less than normal glass house conditions the crop with this certain type of modifications can produces better results in that special glass house conditions. The crop matures within half time of crop grown in normal glass house conditions.

Speed breeding was first initiated by US NASA targeting to raise wheat in space using extended photoperiods or constant light and precise temperature in order to overdrive photosynthesis and hasten plant growth. Dr Lee Hickey and his co-workers were the first to adopt NASA Plan for the production of wheat and peanut at the University of Queensland, John Innes Centre and the University of Sydney in Australia.

The experiments done on wheat revealed that the yield and the quality of plants grown under controlled climate with extended daylight were the same as those of crops grown in regular glasshouse conditions (Shivakumar *et al.,* 2018). Traits that we can measure using speed breeding are: Green Revolution dwarfing genes, Awn suppressor genes, Fusarium head blight resistance, Rust resistance, Glaucousness and Tan spot resistance (Tarek*et al.,* 2018).

In comparison to plants grown in field, by using simple techniques of extended photoperiodic conditions (normally 22 hour light and 2 hour dark photoperiod) by using combination of light emitting diodes (LED) and metal halides in temperature controlled growth chambers results in rapid advancement of generations. This has been successfully used to achieve 6 generations per year in *Hordeum vulgare* (barley), *Triticum durum* (durum wheat), *Triticum aestivum* (spring bread wheat), *Cicer arietinum* (chickpea), *Pisum sativum* (pea) and4 generations for *Brassica napus* (canola) as compared against 2-3 generations per year obtained through normal glasshouse conditions. The plants obtained through speed breeding have normal developmental process, can be easily crossed and have high seed germination.

Concept: Using controlled lighting and temperature control conditions plants complete their traditionally long breeding cycle in relatively shorter time by decreasing their time to flower and obtaining seed set, thereby increasing the number of generations obtained per year. For example in Arabidopsis thaliana, by manipulating the ratio of plant hormones and photoperiod along with the germination of immature seeds, 10 generations per year can be obtained by reducing the time to flowering to 20- 26 days. Similarly in case of barley (Hordeum vulgare) using the method of Single Seed Descent, by manipulating the photoperiod, temperature, soil fertility and using techniques of immature seed germination and embryo rescue 9 generations per year can be obtained by decreasing the flowering time to 24-36 days.

Methods:

Speed breeding I - Controlled-environment chamber speed breeding condition

Speed breeding II - Glasshouse speed breeding conditions

Speed breeding III - Homemade growth room design for low cost speed breeding.

Speed breeding I: Controlled environment chamber conditions (John Innes Centre, UK)

- Photoperiod: 22Hrs (light)/ 2Hrs Dark
- Temperature: 22°C (photoperiod)/ 17°C (Dark)
- Humidity: 70%
- Light: white LED, far-red LED & Ceramic metal hydrargyrum quartz iodide lamp
- In wheat the intensity is 360-380 μ mol m^{-2} s^{-1} during vegetative stages and 490-500 μ mol m^{-2} s^{-1}at adult stage.

SPEED BREEDING II: GLASSHOUSE CONDITIONS (HICKEY LAB, UNIV. OF QUEENSLAND, AUSTRALIA)

- A temperature-controlled glasshouse fitted with high pressure sodium vapour lamp
- Photoperiod: 22Hrs (light)/ 2Hrs Dark
- Temperature: 22°C (photoperiod)/ 17°C (Dark)
- Humidity: 70%
- Light Intensity: 440-650 (Adult Plant height) μ mol m^{-2} s^{-1} (approximately 45cm above bench height).

Speed breeding III: Low-cost homemade growth room design (Hickey Lab, of Queensland, Australia)

- Photoperiod: 12Hrs-12Hrs (Light-Dark) for four weeks then increased to 18Hrs-6Hrs
- Temperature: 21°C (photoperiod)/ 18°C (Dark)
- Light: 7 -8 LED light boxes (Grow Candy)
- Intensity: 210–260 (bench height) & 340–590 (Adult Plant height) μ mol m^{-2} s^{-1}.

Need of speed breeding: The need of speed breeding in current era is very much essential because of various disadvantages in current plant breeding technologies. The present breeding technology is much slower process to develop variety it take years to release a new variety and availability of variability among genotypes are depleting because of excessive self-pollination & homozygosity in plants. The biggest challenge of breeding higher yielding and more resilient crops is the inability to complete more generations in lesser time Certain crop species, such as radish (*Raphanus sativus*), pepper (*Capsicum annum*) and leafy vegetables such as Amaranth (*Amaranthus* spp.) and sunflower (*Helianthus annuus*) responded positively to increased day length. Speed breeding of short-day crops has been limited because of their flowering requirements. It is possible to develop successive generations of improved crops for field examination via SSD, which is cheaper compared to the production of DHs. For the photosensitive crops like soybean, speed breeding is not suitable to speed up the breeding cycles. To overcome that we need powerful breeding technology to increase the pace of breeding technologies as well as developing much quality and new cultivars which helps to cope up current changing climate.

Earlier approaches to hasten breeding cycles:

(a) Shuttle breeding: The objective of speeding the process by growing two successive plantings per year. It was originally used at the International Maize and Wheat Improvement Center (CIMMYT) by Norman E. Borlaug.

(b) Double Haploids Technology (DH): A doubled haploid is a genotype formed from haploid (n) cells through random chromosome doubling or artificially induced chromosome doubling methods such as colchicine. *In vitro* haploid production using anther culture, microspore culture or embryo culture using wheat × maize crosses followed by chromosome doubling greatly enhances the production of homozygous wheat lines in a single generation and increases the precision and efficiency of the selection process in wheat breeding. It also enables detection of linkage and gene interactions, estimating of genetic variance and the number of genes for quantitative traits. Doubled haploid allows shortening the cycle in wheat by 16 to 50% depending on the growth habit (spring or winter) and the generation from which the DH are produced (F_1, F_2, BC_1F_1, *etc.*). In a normal breeding strategy, only after at least 6 generations the level of homozygosity is large enough to undertake genotype screening and preliminary yield trials.

Examples of speed breeding in crop improvement:

(1) Cereals: Researchers have explored novel approaches to reduce the time required to obtain homozygous lines after hybridization to expeditiously breed cereal varieties. For example, four to six generations of wheat were obtained following the harvesting of immature seeds after 15–20 days of anthesis and the treating of the seeds with H_2O_2 at a low temperature (Zheng *et al.,* 2013). A later study by De Pauw and Clarke improved the germination response of wheat seeds by extending the duration of H_2O_2 treatment at a low temperature (11 ◦C) and depending upon the cultivar, the generation time was reduced by 12–23 days. The SB techniquehas been used efficiently in wheat for the rapid screening of multiple traits related to diseases, such as leaf rust, and root architecture and for evaluating plant height and flowering time. SB has been implicated for screening drought-tolerance traits in barley.A modified, backcrossing methodology, in combination with SB, was used for two years in the development of resistant lines of barley that were otherwise susceptible to different diseases including rust and spot blotch. Similarly, the embryo rescue method and direct germination of immature seeds can be applied in sorghum to significantly reduce the time required for the breeding cycle (Dubcovsky *et al.,* 2006; Yan *et al.,* 2004). Increasing the photoperiod and a foliar mineral supplement are also shown to reduce time to anthesis for a higher generation turnover in oats.

(2) Oilseeds: The possibility of viable seed production through precocious germination was shown in soybean. Later, Roumet and Morin demonstrated a growth cycle truncated from 130–140 to 65–70 days using precocious germination of immature, pre-treated pods. Nagatoshi and Fujita developed a standardized rapid generation advancement protocol for high-quality, Japanese, soybean cultivar Enrej, which reduced crop duration from 102–132 days to 70 days. The availability of such methods enables five generations per year instead of one to two generations in a year. In the same way, Watson *et al.,* optimized an SB protocol in canola to enhance the generation turnover and facilitate phenotyping of the pod-shattering trait. For this, five canola cultivars susceptible to pod shattering were grown in environment-controlled growth chambers. Using the embryo rescue technique, Dagustu *et al.,* established a short breeding period protocol for sunflower that can be used to shorten the generation time in a breeding program. For this, seed embryos were cultured in MS media with 2% sucrose and 0.8% agar at pH 5.6–5.7 after 10–12 days of pollination, as previously used in tobacco.

(3) Fruit crops: Many fruit crops undergo a long juvenile phase before flowering, in some cases, taking >20 years. SB techniques have led to vigorous vegetative growth and early flowering in apple (ten months instead of five years) and chestnut (two years instead of seven years). The development of a new cultivar with desirable traits was achieved in apple using SB technology, which is based on transgenic, early-flowering plants and MAS. Several of the clonally propagated crops, such as banana, roots and tubers (not fruit crops), have begun to utilize SB in order to reduce flowering time and increase flowering rate, as well as the predictability of flowering, for the introduction of disease resistance traits, as exemplified by bacterial wilt in banana.

(4) Vegetable crops: Extending the photoperiod has shortened generation intervals in vegetables, such as pepper, tomato and amaranth, which respond effectively to increased daylight. In tomato, germination of immature seeds from different maturity levels provided new possibilities to achieve five generations instead of the conventionally grown three. Similarly, in pepper and tomato, in vitro germination of immature embryos enabled authors to obtain one more generation compared to conventional breeding practice. In grain amaranth, photoperiod manipulation was reported to be helpful in flowering synchronization in different germplasm lines, which, in combination with DNA marker technology, led to the development and identification of true hybrids, thus, accelerating the breeding program. Other methodologies that can improve generation turnover in vegetables by promoting early flowering involve higher expression of flowering genes such as the CaFT-LIKE gene in pepper. Similarly, asdemonstrated by Velez-Ramirez *et al.,* (2014), in tomato, introgression of the gene CAB-13 canimpart tolerance to continuous light, thus, adapting plants to extended photoperiods.

Role of speed breeding in enhancement of crop plants:

(1) Integrated phenotyping with speed breeding as a tool for improving yield: Any breeding selection method starts with phenotyping. Modern plant phenotyping, on the other hand, evaluates complex traits related to growth, yield, and stress adaption with greater accuracy and precision at many scales of organization, from organs to canopies. The assessment of complex plant traits such as growth, development, tolerance, resistance, architecture, physiology, ecology and yield, as well as the basic measurement of individual are quantitative parameters (Springer and Ward, 2007). The dynamic and local interaction of phenotypes with the spatially and temporally dynamic environment above and below ground gives rise to the plant phenotype. Plant biomass, root morphology, leaf feature sand fruit traits are all examples of structural and functional aspects that can be directly quantified.

(2) Gene editing in combination with speed breeding for crop improvement: Traditional plant breeding has been successful in producing excellent crop varieties, genetic quality has decreased in the current era due to continual selection and long-term domestication of crops, and this is one of the limiting factors for crop quality development. In this era, genome editing technology has proven to be beneficial. Gene editing is a technology that involves making changes to the genes of a crop species to improve its yield. Wolter *et al.,* (2019) examined the power of CRISPR-cas9 to generate genetic diversity at several sites. It targets the actual problem and a high yielding variety can be developed but this process takes longer duration of time and requires large amount of effort. Integration of genome editing and speed breeding has power to overcome this crises by shortening the generation time.

(3) Speed breeding to accelerate domestication: Plant domestication is the process of transforming wild plant varieties into crop plants via artificial means. Early hybridization is followed by a selective breeding approach in this procedure. Plant breeding is especially connected to polyploidy crops (Hatfield & Prueger 2015; McClung *et al.,* 2016). It is a time-consuming technique, thus to address this issue, it has been integrated with speed breeding, which minimizes the time duration and number of generations of that crop that has been issued. Plant domestication proof has to be found in polyploidy plants like peanuts and bananas, in combination with rapid breeding. O'Connora *et al.,* undertook a study to determine the feasibility of using the speed breeding approach in peanut breeding. In comparison to the regular breeding phase, this study reduces the time it takes to produce multiple generations in a shorter period.

(4) Multiple disease resistance by speed breeding: Plant breeders are experimenting with new approaches to improve crop production quality to respond faster to changing climates and emerging diseases. Lee T. Hickey *et al.,* combined the two-row barley cultivar, Scarlett, with novel approaches for rapid trait introgression in a study. They developed 87 BC1F3:4 Scarlett introgression lines (ILs) in two years using four donor lines with multiple disease resistance and a redesigned backcross method that included phenotypic multi-trait screens as well as fast generation advanced technology 'speed breeding'.

(5) Speed breeding with SNP Marker-Assisted Selection reducing salt tolerance: Climate change would intensify a number of plant abiotic stresses including salinity, heat and drought etc. thus reducing growth. Salinity is having severe effect on the metabolism, growth and productivity worldwide. Rana *et al.,* developed a new salt tolerant line "YNU31-2-4" in Rice through single nucleotide polymorphism (SNP) marker assisted selection. As it is a slow process, speed –breeding technique is used to accelerate the generation advancement.

(6) Speed breeding as a tool in other breeding methods: Speed breeding can be used as a rapid generation advancement tool in other conventional breeding methods to advance a generation in very less time in crops by using this technology in different phases of other breeding methods.

Conventional breeding technology along with speed breeding technology helps to maintain good relationship with nature and improves the speed of current conventionalbreeding technology in general in traditional breeding method of plant breeding we can yield of 1 or 2 maximum but by using speed breeding technology we can boost up the pace of traditional breeding methods for to completing 6 generations of crop within year and jump in to next crop this advance tool rapidly drives and improves and save time by developing a variety with pace along with growing population around the globe it also helps to maintain thestability of crops and increase the productivity, food security rapidly.

Combining speed breeding technology with other state-art-technologies: Speed breeding has a lot of potential to completely change present scenario of current plant breeding technologies by combining with state art technologies like with other molecular approaches, genome editing technologies like CRIPSPR-CAS9 its saves lot of time and it helps the plant breeders snip out the yield reducing or other vulnerable traits from the crop and advancing the crop generation with rapid pace speed breeding can be done in diploid crops then polyploid crops because of their complex genomics

- Speed breeding can also be utilized to boost up the transgenic approaches of crop improvement.
- Scientists are also applying speed breeding system to speed up the double haploid program.
- The approach has also been adapted for high density plant production systems for SSD programs
- Generation time was shorter than for plants grown at lower density in previous speed breeding experiments.
- Higher density may cause stress or plant competition, lead to hasten flowering.
- Speed breeding and marker assisted selection: For genetically well-defined traits, speed breeding could be used to rapidly introgress genes or haplotypes into elite lines using marker-assisted selection.
- The speed breeding system is potentially relevant for the rapid development of RIL‟s which are essential for molecular marker discovery.
- Speed breeding and Association mapping: To track and confirm the presence of target regions.
- Speed breeding and genomic selection: Pyramiding of multiple traits and to enable selection for yield and grain quality traits.
- The speed breeding / SSD system is ideally suited to a backcrossing breeding strategy.

Opportunities of speed breeding techniques:

(1) Rapid development of homozygous lines for accelerated breeding: Speed breeding techniques have been used on various crops to rapidly develop homozygous lines after initial crosses of selected parents with complimentary traits. The technique depends on the manipulation of photoperiod, light intensity, temperature, soil moisture, soil nutrition and high-density planting. These methods have been used to induce early flowering and seed set, reducing the time taken to generate each breeding generation. The method allows for the production of 3 to 9 breeding generations per year. This is ideal for accelerated breeding and population evaluation across the target production environments involving various selection methods such as SSD, SPD and SPS (El-Hashash & El-Absy, 2019). Speed breeding relies on deliberate manipulation of various growing conditions that are described below.

(2) Amenability with selection methods: Speed breeding is routinely used for generation advancement without phenotypic selection. However, modern technologies (e.g. high throughput genotyping methods, marker-assisted selection, etc.) can be successfully integrated for target traits selection (Vince-Prue *et al.,* 1994). The combination of speed breeding and effective selection methods should allow for the maintenance of a good breeding population and genetic diversity in the environments that restrict plant growth, and for maximum yield production (Johnston *et al.,* 2019). Conventional selection methods such as bulk, mass, recurrent, pedigree and pure line selection require a genetically stable plant population for selection of optimally yielding genotypes. These methods are not ideal for speed breeding dueto the long inbreeding and selection cycles that they require. The most appropriate selection methods amenable with speed breeding are single seed descent (SSD), single pod descent (SPD) and single plant selection (SPS) methods. These methods are briefly described below (Kouressy *et al.,* 2008; Saito *et al.*, 2009).

(3) Single seed descent method: Single seed descent (SSD) is geared towards achieving homozygous populations through continuous inbreeding of segregating population by retaining one seed from each F2 plant and advancing these individuals to the next generation (Destro *et al.,* 2003). Each inbred line developed is traced back to an F2 plant (Fehr, 1991). The time taken to achieve inbred lines with SSD is comparable to that of the doubled haploid (DH) method (Yan *et al.,* 2017). The advantages of the SSD selection method include less growing area and labour being required for the handling of early generations. It allows for the advancement of progeny under high-density plantings in small nurseries, growth chambers or greenhouses (Arbelaez *et al.,* 2019; Funada *et al.,* 2013). In maize, Bordes *et al.,* (2007) found non-significant differences in the grain yield of inbred lines developed from the same parental genotypes usingthe doubled-haploid (DH) and SSD methods. Ma *et al.*, (1999) reported that the mean grain yield and kernel weight of SSD lines was higher than those of anther culture derived lines in maize and spring wheat. Overall, SSD is the best selection method for speed breeding and canbe carried out under both field and indoor conditions.

(4) Single pod descent method: Single pod descent (SPD) method involves selection of one podper plant from each F2 – F4 plant instead of a single seed. Due to there being more than one seed per pod in most legume crops, SPD has a higher chance of maintaining each F2 plants in the advanced generations than SSD selection**.** Funada *et al.*, (2013) reported that progenies developed from crosses between soybean cv. 'OAC Atwood' and 'RG600RR', with a mean of seeds per pod, increased the population from 200 in the F2 to 300 plants in the F3 generation. They found non-significant differences in selection efficiency for lines developed using the SSD, SPD and bulk methods (Tanaka *et al.,* 2016). Another advantage of SPD is thatit allows for the early selection of pods, so a smaller population can be advanced.

(5) Single plant selection method: The single plant selection (SPS) method advances each F2 plant by harvesting all the seeds of each selected plant. Hence the next generation will be advanced as plant-to-row. The SPS method has been used in a modified backcross strategy to develop introgression lines (ILs) within two years in barley (Hickey *et al.,* 2017). In bread wheat, Alahmad *et al.,* (2018) used the SPS selection method to enhance foliar disease resistance, grain dormancy, seminal root angle, seminal root number, tolerance to crown rot, resistance to leaf rust and plant height in an approach that is compatible with speed breeding.

Challenges of speed breeding: The use of speed breeding techniques is a valuable approach to accelerate conventional breeding programmes. However, the technology requires expertise, effective and complementary plant phenomics facilities, appropriate infrastructure and continuous financial support for research and development (Shimelis *et al.,* 2019). For these resource to be in place requires that speed breeding approaches are recognized as essential for conventional plant breeding, marker assisted-selection and genetic engineering. Furthermore, the integrated suite of tools requires skills and expertise in plant breeding and biotechnology, long-term funding and government policy support. For example, in Sub-Saharan Africa (SSA) most public plant breeding programmes use traditional plant breeding approaches. Use of modern breeding tools in the public sector is limited by technical, economic and institutional challenges (Morris & Bellon 2004). Speed breeding methods could accelerate the release of both conventional and genetically modified crop cultivars in SSA. However, the most common challenges hampering the use of speed breeding include:

- Access to suitable facilities
- Staff trained in the protocol
- Adopting major changes to breeding programme design and operations
- The need for long-term funding.

A lack of trained plant breeders and breeding technicians: A major challenge that can hamper the adoption of speed breeding in the public sector is a lack of trained and active plant breeders, and plant breeding technicians in developing countries **(Morris *et al.*, 2006, Shimelis *et al.*, 2019).** The public sector breeding programmes are negatively affected by a high turn-over of plant breeding personnel to private seed companies and training institutes that offer better remuneration than government service. Moreover there are relatively few scientists specializing in plant breeding because postgraduate qualifications in plant breeding are only offered at a few universities in developing countries. In some countries, the legislative and administrative framework to manage plant breeders' rights and seed regulation have not been developed to encourage plant breeding to benefit the value chain from farmers to consumers **(Tripp *et al.*, 2007).** Therefore, developing countries need to adjust their policies and practices related to investments in plant breeding education, research and personnel retention to ensure the viability of long-term crop improvement programmes, and the adoption of scientific innovations such as speed breeding.

Inadequate infrastructure: Speed breeding platforms require sophisticated infrastructure to regulate environmental factors, particularly soil moisture, temperature and photoperiod. Institutional support is limited in public plant breeding programmes in many developing countries. This limits the adoption of state-of-the-art breeding methods such as speed breeding and biotechnological tools **(Byerlee & Fischer, 2002).** Moreover specialized equipment needed to carry out selection of traits during early generation advancement are limited **(Ribaut *et al.*, 2010).** Additionally, an overreliance on donor agencies ('donor mind-set') and a lack of harmonization of regional breeding programmes leads to duplications of activities and investments in resources. Therefore, there is a need for active collaboration between national and regional organizations in the development of infrastructure, and for resource and knowledge sharing once the infrastructure is in place. An opportunity exists to reduce the costof establishing new infrastructure by the invention of innovative, local equzipment, such as theuse of modified shipping containers fitted with solar-powered temperature and light control equipment **(Chiurugwi *et al.*, 2018).**

Unreliable water and electricity supplies for sustainable operations: The manipulation of environmental factors, specifically moisture, temperature and photoperiod, indoor growing facilities requires reliable water and electricity supplies. Indoor speed breeding facilities require affordable, sustainable and reliable energy for cooling, heating and lighting. For instance, the cost of temperature regulation in Queensland during winter accounted for more than half of the total cost of plant management **(O'Connor *et al.*, 2013).** Unreliable supplies ofelectricity are a major problem for the management of temperature and photoperiod for speedbreeding in public plant breeding programsmes. Growing crops in the field require land preparation, fertilization, irrigation and other standard agronomic practices, which have substantial costs and require substantial infrastructure investments. In developing countries, speed breeding will require innovative solutions to the supply of water and electricity, such as the use of sustainable solar power. A small indoor speed breeding kit consisting of fitted LED lights and temperature controls powered by a solar system with battery backup could be developed using existing technologies. An alternative would be adapting the principles of speed breeding to semi-controlled field-based systems, where high-dense planting, combined with moisture and nutrient stress can be managed, but large populations can be grown at a relativelylower cost.

Applications of speed breeding:

1. Accelerating the crop improvement programmes by achieving upto 6 generations per year in photo insensitive crops and 2-3 generations in case of photo sensitive crops.
2. Speeding up the process of genomic selection.
3. An ideal method for generating large breeding populations.
4. For boosting transgenic and CRISPR pipelines.
5. It can be extended to study physiological traits of importance in crop plant

Advantage of speed breeding:

1. Multiple generations in one year
2. Fast way to obtain fixed homozygous lines through Single Seed Descent method
3. Phenotypic selection in early segregating generations
4. Rapid introgression genes into elite lines using Marker Assisted Selection
5. Allows study of plant-pathogen interaction, flowering time etc.
6. Multi- environmental trail across years
7. Integrated with genomics selection, genome editing etc.
8. High – throughput phenotypic screens for multiple traits
9. Exploit gene bank accessions and mutant collection for rapid gene discovery

Limitation of speed breeding:

1. Extended photoperiods may cause injury in some crops

2. Unlikely to be successful in short-day crops
3. Disease outbreak using controlled environmental conditions
4. Plant losses in Single Seed Descent during greenhouse condition
5. Increased monetary costs
6. Incorporation of relatively simple inherited traits
7. The early harvest of immature seeds before completing normal ripening processinterferes with the phenotyping of some seed traits.
8. There is no universal protocol of speed breeding because of diverse response of plant species to photoperiodic conditions.
9. Differential responses of various plant species when exposed to extendedphotoperiodic conditions.
10. Initial investment of setup is high.

Future of speed breeding:

Speed breeding likely to reduce generation time for other crop species, such as sunflower, pepper and radish which have been shown to respond well to extended photoperiod. The future of speed breeding holds promise and potential in several key areas:

(1) Precision breeding: As our understanding of plant genetics and genomics continues to advance, speed breeding will likely become more precise. This will enable breeders to target specific genes and traits with even greater accuracy, reducing the need for trial and error in crop improvement.

(2) High-throughput technologies: Ongoing advancements in high-throughput technologies, such as automated phenotyping and genotyping, will further streamline the speed breeding process. This will enhance the efficiency of selecting and propagating desirable traits.

(3) Data-driven approaches: The integration of big data, artificial intelligence, and machine learning into speed breeding will help analyze vast amounts of genetic and environmental data. This will assist in identifying key genetic markers and optimizing growth conditions for improved crop development.

(4) Climate-resilient crops: Speed breeding will play a vital role in developing crops that are more resilient to climate change. Faster breeding cycles will allow for the rapid selection and breeding of crops with increased tolerance to extreme temperatures, drought, and other environmental stresses.

(5) Customized crops: Speed breeding will enable the creation of customized crops tailored to specific regions and needs. Breeders can develop crops that thrive in local conditions, resultingin higher yields and better food security.

(6) Biotechnology integration: Speed breeding will likely see more integration with biotechnology, including genetic engineering techniques like CRISPR-Cas9. This could facilitate the quick introduction of beneficial traits and reduce the time needed to develop new varieties.

(7) Expanded crop variety availability: The speed breeding approach is not limited to a few major crops; it can be applied to a wide range of crops, including orphan and underutilized species. This will broaden the availability of improved crop varieties for diverse agricultural systems.

(8) Resource efficiency: Speed breeding will continue to promote resource efficiency in agriculture. By reducing the land, water, and other resources needed for breeding programs, it can contribute to sustainability in food production.

(9) Global collaboration: The future of speed breeding will likely involve increased collaboration between researchers, institutions, and countries. Sharing knowledge and techniques will help accelerate progress and improve crop improvement efforts on a global scale.

(10) Regulatory considerations: As speed breeding methods become more advanced and biotechnology applications more widespread, there will be ongoing discussions about regulations and safety considerations to ensure the responsible use of these technologies.

(11) Consumer preferences: Speed breeding can be used to develop crops that align with changing consumer preferences, such as crops with better taste, extended shelf life, or specific nutritionalprofiles.

(12) Crop diversity conservation: Speed breeding can be used to preserve and propagate endangered or underutilized crop varieties, contributing to the conservation of agricultural biodiversity.

Overall, the future of speed breeding is closely tied to advancements in science and technology,and it will continue to be a key driver of innovation in agriculture. This method has the potential to address the evolving challenges facing the agricultural sector, from climate change and population growth to the need for sustainable, resource-efficient, and resilient crop production.

Achievements:

By speed breeding program, growing up to six generations per year is possible in wheat, barley, chickpea and up to four generations of canola. Speed breeding is also applied in pea, peanuts, grass pea, amaranth, quinoa, Brachypodium, Medicago and many more crops. The technique is responsible for the development of “DS Faraday” wheat variety, which is a high protein, milling wheat with tolerance to pre-harvest sprouting Tarek *et al.*, (2018).

“Scarlett” is the most extensively cultivated cultivar of barley in Argentina, which is susceptible to many diseases. By taking four lines with a modified backcrossing method, resistant lines were developed within two years Hickey *et al.,* (2017). Moreover, drought tolerance trait in barley can also be achieved by speed breeding Ghosh *et al.,* (2018).

“YNU31-2-4” a Salt tolerant rice variety, was developed with the help of speed breeding. The gene was inserted by SNP marker, and the breeding cycle accelerated by speed breeding (14h light/10h dark- germination to 30 days of germination, ten h light/14h dark reproductive phase). The tillers were removed, and the embryo rescue technique was used to save time before seed maturity. Thus, enabling the researchers to get 4 to 5 generations of rice per year as reported by Rana *et al.*, (2019).

Speed breeding surpasses "shuttle breeding" and produces three times a greater number of generations. With shuttle breeding, only two generations per year can be achieved, while with speed breeding, up to 6 generations can be obtained Ortiz *et al.*, (2007).

Conclusion:

Speed breeding is a form of protocol that can be used to increase agricultural yield by altering the light duration, intensity and temperature-controlled zone, as well as the generation of disease-resistant varieties and lowering salt sensitivity in crops. The photosynthetic process is improved via speed breeding, resulting in faster crop development. In comparison to traditional breeding, this approach allows for the release of several generations of the same crop in a shorter amount of time. Speed breeding is a revolutionary technique for rapidly creating new long-day plant cultivars by lowering the generation time. To address food security challenges, more generation times each year are required. By lowering the amount of time, space, and resources invested in the selection and genetic progression of superior crop varieties, speed breeding can hasten the production of high-performing cultivars with market-preferred features.

With the ever increasing population, by 2050 farmers will have to increase food production by 60-80% to feed the potential 9 billion people. Another main issue which arises is that breeding programmes should be in tandem with the changing climatic conditions and to achieve rapid results in both these respects, speed breeding is the way to go. In India, where resources are very limited, speed breeding can be one of the most viable options to shortening the breeding cycle and accelerating the research program. Speed breeding can serve to enhance the plant growth by accelerating research program in terms of reducing the breeding cycle of plant. Particular success has been seen in case of wheat in speed breeding which can be extended to other crop varieties, and similar facilities can be set up for the faster development.

Speed breeding combined with new technologies like marker-assisted selection, genomic selection, CRISPR gene editing etc. can help to improve the selection of elite genotypes and lines with innovative features like improved yield and nutritional quality, as well as biotic and abiotic stress tolerance. The most suitable selection strategies are compatible with rapid breeding. However, in many developing countries, particularly in public plant breeding programs, the adoption of speed breeding is limited due to a shortage of skilled plant breeders and plant breeding technicians, as well as a lack of the necessary infrastructure and reliable water and electricity sources. There is now a lack of regulatory and financial support from the government to launch and continue speed breeding in public plant breeding programs. To accelerate the production, testing, and commercial release of crop varieties, speed breeding must be combined with other breeding techniques as well as cost-effective high-throughput genotyping and phenotyping. In general, plant biologists can scale up their crop improvement research by combining speed breeding with genetic tools and resources. Speed breeding protocols that reduce plant production times can help accelerate breeding and research to meet rising demand.

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MILLET: A COMPLETE CEREAL GRAIN

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Abstract:

Millet is a small, round whole grain grown in India, Nigeria, and other Asian and African countries. Millets are highly adaptive to a wide range of ecological conditions and thrive well in rain-fed, arid climates. They require minimal water, fertilisers, and pesticides. Millet is rich in phenolic compounds, especially ferulic acid and catechins, which act as antioxidants protecting the body from oxidative stress. Known as "coarse cereals" or "cereals of the poor," Indian millets are nutritionally superior to wheat and rice, being rich in protein, vitamins, and minerals. They are gluten-free and have a low glycemic index, making them suitable for people with celiac disease or diabetes. India ranks among the top 5 exporters of millets globally, underscoring their importance for food security and economic stability.

Keywords: Phenolic Compounds, Antioxidants, Coarse Cereal, Gluten-Free, Glycemic Index, Celiac Disease, Oxidative Stress

Introduction:

Millet is a staple food in many parts of Africa and Asia, with approximately 1.2 billion people including it in their diet (World Food Programme). The production of millet, primarily in Africa and Asia, was estimated at 28 million metric tons in 2020. India leads in millet production, followed by Niger and China. Indian millets are known for their nutritional richness, drought tolerance, and suitability for arid and semi-arid regions. They are members of the Poaceae family, commonly referred to as grasses. India also dominates global millet exports, with figures rising from $400 million in 2020 to $470 million in 2021 (ITC trade map). Millets play a crucial role in India's National Food Security Mission and are expected to see continued growth in production. The graph below illustrates millet production trends in India.

Types of Millets

Millets vary in size and color but belong to the grass family, similar to wheat, rice, and barley. They can be categorized into major and minor types:

Large Millets:

- **Pearl Millet**: Commonly white, yellow, grey, or purple, with grains ranging from 3-5 millimeters.
- **Sorghum**: Available in white, yellow, and red shades, grains are 4-6 millimeters.
- **Finger Millet (Ragi)**: Typically brown, with grains sized 1-2 millimeters.
- **Foxtail Millet**: Grains are 2-3 millimeters and vary in color from red and black to white or yellow.

- **Proso Millet**: Grains are about 3 millimeters with variations in white, yellow, or brown colors.

Small Millets:

- **Little Millet**: Grains are 2-3 millimeters and come in grey and white shades.
- **Barnyard Millet**: Grains are about 3 millimeters, available in grey and white shades.
- **Kodo Millet**: Grains range from black to dark brown, about 3-4 millimeters.
- **Browntop Millet**: Grains are tan to white, approximately 4-5 millimeters.

Major Millets

- **Sorghum (Jowar)**: Prolamin-rich protein with unique digestibility benefits. Rich in protein, fiber, vitamins, and minerals like potassium, phosphorus, calcium, iron, zinc, and sodium.
- **Pearl Millet (Bajra)**: High protein and lipid content, significant dietary fiber, and rich in niacin, folic acid, magnesium, iron, copper, zinc, vitamins E and B-complex.
- **Finger Millet (Ragi)**: Richest calcium source, high mineral content, lower protein and fat levels, and excellent malting properties.

Minor Millets

- **Foxtail Millet (Kakum)**: High carbohydrate and protein content, rich in copper and iron.
- **Kodo Millet (Kodon)**: High protein, low fat, very high fiber content, rich in B vitamins, niacin, pyridoxine, folic acid, and essential minerals.
- **Barnyard Millet (Sanwa)**: Richest source of crude fiber and iron, contains Gamma amino butyric acid (GABA) and Beta-glucan.
- **Little Millet (Kutki/Shavan)**: Smaller size, high iron content, and strong antioxidant properties.
- **Proso Millet (Chenna/Barri)**: Highest protein content, significant carbohydrate and fatty acids, rich in calcium.

Pseudo Millets

- **Amaranth (Ramdana/Rajgira)**: High protein and oil content, rich in dietary fiber, iron, magnesium, phosphorus, potassium, and bioactive peptides.
- **Buckwheat (Kuttu)**: High protein, rich in lysine, carbohydrates, vitamins B1, C, and E, polyunsaturated fatty acids, zinc, copper, manganese, and soluble fiber.

Nutritional Benefits of Millets (per 100g)

- **Sorghum**: Protein 10g, Fiber 4g, Iron 2.6mg, Calcium 54mg
- **Pearl Millet**: Protein 10.6g, Fiber 1.3g, Iron 16.9mg, Calcium 38mg
- **Finger Millet**: Protein 7.3g, Fiber 3.6g, Calcium 344mg
- **Foxtail Millet**: Protein 12.3g, Fiber 8g, Iron 2.8mg, Calcium 31mg
- **Proso Millet**: Protein 12.5g, Fiber 2.2g, Iron 0.8mg, Calcium 14mg
- **Kodo Millet**: Protein 8.3g, Fiber 9g, Iron 0.5mg, Calcium 27mg
- **Little Millet**: Protein 7.7g, Fiber 7.6g, Iron 9.3mg, Calcium 17mg

- **Barnyard Millet**: Protein 11.2g, Fiber 10.1g, Iron 15.2mg, Calcium 11mg
- **Teff**: Protein 13g, Fiber 8g, Iron 7.6mg, Calcium 180mg
- **Fonio**: Protein 11g, Fiber 11.3g, Iron 84.8mg, Calcium 18mg
- **Browntop Millet**: Protein 11.5g, Fiber 12.5g, Iron 0.65mg, Calcium 0.01mg

Health benefits of millets:

Highly adaptable to ecological conditions, low glycemic index, gluten-free, rich in minerals, beneficial for diabetes prevention, management of hyperlipidemia and cardiovascular diseases, weight and blood pressure reduction, and enhanced protein digestibility.

How to cook millet:

Millet can be bought in various forms—dried, puffed, or ground as flour. Dried millet can be cooked like couscous or quinoa. Millet flour serves as a wheat flour substitute. Puffed millet can be enjoyed as a snack or used in place of puffed rice cereal. For cooking, combine 1 cup millet with 2 cups water, bring to a boil, simmer for 15 minutes covered, then let stand for 10 minutes. Pre-soaking reduces phytic acid content for better nutrient absorption. Toasting adds nutty flavor.

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