Original Research Article

Exploring the storage potential of groundnut var.TMV (Gn) 13under Modified Atmospheric Storage conditions

ABSTRACT

The lab experiment was conducted to assess the storage potential of groundnut (*Arachis hypogaea* L.) variety TMV (Gn) 13 under modified atmospheric storage conditions during 2022 at Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore. The groundnut pods and kernels were subjected into different storage conditions *viz.,* kernels pods stored in gunny bag, kernels stored in gunny bag, kernels stored in polythene bag, kernels stored with N_2gas and kernels stored in vacuum conditions. The results revealed that pod storage recorded the maximum germination percentage(73%),root length(14.5cm), shoot length(14.3cm),dry matter production (3.47 g 10 seedlings $^{-1}$) and vigour (2136). Similarly, enzymes viz., dehydrogenase, peroxidase, alpha amylase and catalase activity were also maximum in pod storage and nitrogen storage conditions with minimum harmful effect of pest and fungus incidence. Present study, it is concluded that groundnut kernels stored under modified atmospheric storage i.e. nitrogen gas storage can maintain the seed longevity by minimizing the deterioration process in groundnut equally as that of pod storage. Further, it will helps to minimize the expenditure towards transport and storage.

Comment [S1]: Enter the driving factors for carrying out this research

Comment [S2]: should be equipped with data from the results

***Key words*:** Modified atmospheric storage, Groundnut kernel, Seed storability

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a leguminous plant that is widely cultivated in the tropics and subtropics and it is valued for its high-oil content and edible seeds. It is the fourth most important source of edible oil and a third most important source of vegetable protein in the World. Globally, groundnut covers 327 lakh hectares with the production of 539 lakh tonnes with the productivity of 1648 kg per hectare (FAOSTAT, 2021).Groundnut is valued as a rich source of energy contributed by oil (48–50%) and protein (25–28%) in the kernels and 100 g of kernels provide 567 kcal of energy and 8.5 g of dietary fiber (Murali and Janila, 2017). Additionally, groundnuts are a rich source of minerals, vitamins (Vitamin E, Thiamine, Pantothenic acid, Vitamin B6, Folates, and Niacin) and antioxidants and health improving bioactive compounds such as

resveratrol, tocopherol, arginine, p-coumaric acid, polyphenols, flavonoids, isoflavones,*etc*. The consumption of groundnut and its products can reduce risk of inflammation, diabetes, cancer, alzheimer's and gallstone disease.As they are highly nutritious, groundnut and its products can be promoted as nutritional foods to fight energy, protein, and micronutrient malnutrition among the poor people.Due to high nutrient contents of groundnuts, they have been used to combat the malnutrition in developing countries and also reduce the cardiovascular heart disease and gall stone (Bonkuand Yu., 2020).

Seed of improved varieties is a costly input; more so in the case of groundnut, where the non-availability of improved variety seeds is a major constraint in most of the groundnut-growing countries. The private sector has shown little interest in the groundnut seed enterprise due to the low seed multiplication ratio, bulky nature of the produce, quick loss of seed viability, high cost of transportation, low-profit margin, and the self-pollinated nature of the crop. Quick loss in viability period of groundnut leads to create more seed demand and it indirectly affect the seed multiplication chain. Therefore, availability of good quality seeds at right time with affordable price is a great task to the public sector seed services.

Comment [S3]: enter the source of the theory

The major problem accompanied with groundnut is poor storage because of its possession of polyunsaturated fatty acids which will get break down when there is high temperature and thus results in lipid peroxidation. The seeds produced in one season are not fully consumed in the same season for farm and home, because of its voluminous quantity of production. So the major part of the produce is going for storage to utilize in the next upcoming months either as seed source or food source. The most common method of storage of groundnut was pod storage because of its ability to protect the kernel by limiting the lipid peroxidation. There are numerous techniques such as seed treatment, mid-storage correction to sustain the seed quality during storage. In all this techniques practical difficulties are more. Modified Atmospheric Storage (MAS) is one of the novel approach to protect groundnut kernel with its quality for a longer period compared to kernel under ambient storage. In MAS, the kernels are stored in the atmospheric condition including higher amount of (N_2), (CO_2) and reduced (O_2). In this modified storage condition, the environment that surround the seeds is only altered and does not treated with any material, so it does not pose any health hazard to human, animal and not phytotoxic to the seeds. Seed stored in MAS will reduce the insect population by reducing the temperature that will increase during the respiration of seeds. Riudavets*et al*., (2018) reported that modified atmospheric packaging of maize seed with (90%CO_2,5%$O_2$and 5% N_2) effectively reduce the *Sitophilus zeamis* population by inhibiting all the life stages of insects thereby it control the proliferation of aflatoxin produced during storage of maize seeds.

Keeping all these points in view, the present investigations were undertaken to explore the storage potential of groundnut variety TMV 13 under modified atmospheric storage conditions.

2. MATERIALS AND METHODS

The laboratory experiments were conducted with groundnut variety TMV (Gn) 13 in the laboratory of Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore during the year 2022 and packaging of the groundnut kernelswas done in the Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore with the Modified Atmosphere Packaging (MAP) Unit. The groundnut TMV (Gn) 13 is a red kernel variety released from Oilseeds Research Station, Tindivanam during 2013 and it is widely cultivated in Villupuram, Thiruvannamalai and Coimbatore districts of Tamil Nadu. The kernels were dried to 6.3 per cent moisture content and then subjected into following storage conditions..

Comment [S4]: It is best to complete this research with a map

Treatment details

M_1- Pod stored in gunny bag under ambient condition

M_2- Kernel stored in gunny bag under ambient condition

M_3- Kernel in polythene bag without any treatment under ambient condition

M_4- Kernel stored with N_2 storage under ambientcondition

M_5- Kernel stored in vacuum storage under ambient condition

The seed quality parameters *viz.*, seed moisture content ((ISTA, 2010). seed germination (ISTA, 2013), root length, shoot length, dry matter production, vigour index (Abdul-Baki and Anderson, 1973), insect infestation, storage fungus infection, alpha amylase((Paul *et al.,* 1970), catalase (Aebi 1984),peroxidase (Malik and Sing, 1980),and dehydrogenase value (Kittock and law, 1968)enzyme activities were analyzed at monthly intervalsup to six months of the storage period (P_0, P_1, P_2, P_3,P_4, P_5 and P_6). The data wereanalyzed by Factorial Completely Randomized Design (FCRD) with three replications as suggested by Panse and Sukhatme (1985).

Table1 Influence of modified atmospheric storage on seed moisture content, seed germination, root length and shoot length of groundnut variety TMV 13 Tabel 1 Pengaruh penyimpanan atmosfer termodifikasi terhadap kadar air benih, perkecambahan biji, panjang akar dan panjang tunas kacang tanah varietas TMV 13

Comment [S5]: masukkan hasil

Comment [S6]: Do not cut the table

Period of storage (P)	Seed moisture content (%)						Germination (%)						Root length (cm)					
	M_1	M_2	M_3	M_4	M_5	Mean	M_1	M_2	M_3	M_4	M_5	Mean	M_1	M_2	M_3	M_4	M_5	Mean
P_0	6.3	6.3	6.3	6.3	6.3	**6.3**	94	94	94	94	94	**94**	15.2	15.2	15.2	15.2	15.2	**15.2**
P_1	6.3	6.4	6.3	6.3	6.3	**6.3**	90	86	88	90	87	**88**	15.2	15.0	15.1	15.1	15.0	**15.0**

P_2	6.4	6.6	6.4	6.4	6.4	**6.4**	80	71	74	73	74	**74**	14.8	14.1	14.7	14.8	14.9	**14.7**
P_3	6.5	7.2	6.5	6.5	6.5	**6.6**	75	54	62	72	61	**65**	14.6	13.9	14.5	14.1	14.7	**14.4**
P_4	6.7	7.4	6.7	*6.6*	6.7	**6.8**	66	50	54	61	52	**57**	14.3	13.6	12.5	13.9	13.8	**13.7**
P_5	6.8	7.6	6.8	6.7	6.8	**6.9**	54	42	58	53	50	**51**	14.0	13.5	11.7	13.8	12.9	**13.2**
P_6	7.0	8.0	7.6	7.4	7.3	**7.4**	55	40	46	50	45	**47**	13.8	12.7	11.5	13.3	12.2	**12.7**
Mean	**6.5**	**7.0**	**6.7**	**6.6**	**6.6**		**73**	**62**	**67**	**70**	**66**		**14.6**	**14.0**	**13.6**	**14.3**	**14.1**	
	P		**M**		**PXM**		**P**		**M**		**PXM**		**P**		**M**		**PXM**	
SED	0.068		0.057		0.151		0.608		0.514		1.360		0.124		0.105		0.277	
CD(0.05)	0.135		0.114		0.302		1.212		1.025		2.711		0.247		0.209		0.553	

Table 2 Influence of modified atmospheric storage on shoot length, dry matter production and vigour index of groundnut variety TMV 13

Comment [S7]: masukkan hasil

Period of storage (P)	**Shoot length (cm)**						**Dry mater production (g seedlings^{-10})**						**Vigour index**					
	M_1	**M_2**	**M_3**	**M_4**	**M_5**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**M_5**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**M_5**	**Mean**
P_0	14.7	14.7	14.7	14.7	14.7	**14.7**	3.74	3.74	3.74	3.74	3.74	**3.74**	2810	2810	2810	2810	2810	**2810**
P_1	14.6	14.0	14.3	14.6	14.3	**14.4**	3.68	3.56	3.60	3.66	3.61	**3.62**	2691	2494	2587	2587	2549	**2582**
P_2	14.5	13.9	14.1	14.4	14.3	**14.2**	3.56	3.43	3.50	3.53	3.52	**3.50**	2344	1988	2131	2132	2160	**2151**
P_3	14.4	12.8	13.7	14.3	14.0	**13.8**	3.45	3.33	3.40	3.42	3.40	**3.40**	2175	1414	1748	2044	1750	**1826**
P_4	14.4	12.1	13.4	14.1	13.6	**13.5**	3.36	3.30	3.32	3.34	3.32	**3.32**	1894	1285	1397	1708	1425	**1542**
P_5	14.2	11.9	13.1	14.0	13.0	**13.2**	3.27	3.13	3.21	3.25	3.27	**3.22**	1523	1066	1473	1473	1295	**1366**
P_6	13.7	11.6	12.8	13.2	12.8	**12.8**	3.24	3.11	3.10	3.21	3.20	**3.17**	1512	968	1118	1325	1125	**1210**
Mean	**14.3**	**13.0**	**13.7**	**14.1**	**13.8**		**3.47**	**3.37**	**3.41**	**3.45**	**3.43**		**2136**	**1717**	**1895**	**2011**	**1873**	
	P		**M**		**PXM**		**P**		**M**		**PXM**		**P**		**M**		**PXM**	
SED	0.138		0.116		0.308		0.032		0.027		0.071		0.032		0.027		0.072	
CD(0.05)	0.275		0.232		0.615		0.064		0.054		0.143		0.064		0.054		0.143	

Table 3 Influence of modified atmospheric storage on insect infestation, storage fungus infection and alpha amylase activity of groundnut variety TMV 13

Comment [S8]: masukkan hasil

Comment [S10R9]: set the title and table together

Period of storage (P)	Insect infestation (%)						Storage fungus infection (%)						Alpha amylase activity (mg maltose min^{-1})					
	M_1	M_2	M_3	M_4	M_5	Mean	M_1	M_2	M_3	M_4	M_5	Mean	M_1	M_2	M_3	M_4	M_5	Mean
P_0	0.0	0.0	0.0	0.0	0.0	**0.0**	4	4	4	4	4	**4**	14.01	14.01	14.01	14.01	14.01	**14.01**
P_1	0.0	0.0	0.0	0.0	0.0	**0.0**	8	16	8	8	8	**10**	13.96	13.64	13.73	13.86	13.81	**13.80**
P_2	0.0	0.0	0.0	0.0	0.0	**0.0**	12	24	20	16	16	**18**	13.84	13.52	13.67	13.79	13.71	**13.70**
P_3	0.0	0.0	0.0	0.0	0.0	**0.0**	16	28	24	20	24	**22**	13.74	13.44	13.60	13.70	13.63	**13.62**
P_4	0.0	0.0	0.0	0.0	0.0	**0.0**	20	36	32	24	28	**28**	13.68	13.38	13.51	13.62	13.59	**13.55**
P_5	0.0	4.0	0.0	0.0	0.0	**0.8**	24	40	36	32	32	**33**	13.15	13.09	13.13	13.27	13.23	**13.17**
P_6	4.0	4.0	4.0	4.0	4.0	**4.0**	32	44	40	36	36	**38**	12.94	12.79	12.82	12.83	12.86	**12.84**
Mean	**0.6**	**1.1**	**0.6**	**0.6**	**0.6**		**17**	**27**	**23**	**20**	**21**		**13.60**	**13.41**	**13.49**	**13.58**	**13.54**	
	P		**M**		**PXM**		**P**		**M**		**PXM**		**P**		**M**		**PXM**	
SED	0.017		0.015		0.039		0.209		0.176		0.466		0.132		0.111		0.295	
CD(0.05)	0.034		0.029		0.077		0.416		0.352		0.930		0.263		0.223		0.589	

Table 4 Influence of modified atmospheric storage on dehydrogenase, catalase andperoxidase enzyme activities of groundnut variety TMV 13

Comment [S11]: masukkan hasil

Period of storage (P)	Dehydrogenase activity (OD value)						Catalase activity ($\mu molH_2O_2$ $min^{-1}g^{-1}$ protein)						Peroxidase activity (U mg^{-1} protein min^{-1})					
	M_1	M_2	M_3	M_4	M_5	Mean	M_1	M_2	M_3	M_4	M_5	Mean	M_1	M_2	M_3	M_4	M_5	Mean
P_0	1.00	1.00	1.00	1.00	1.00	**1.00**	1.363	1.363	1.363	1.363	1.363	**1.363**	1.63	1.63	1.63	1.63	1.63	**1.63**
P_1	0.92	0.72	0.82	0.85	0.83	**0.83**	1.358	1.327	1.338	1.345	1.342	**1.342**	1.56	1.40	1.50	1.55	1.54	**1.51**
P_2	0.81	0.66	0.71	0.74	0.73	**0.73**	1.343	1.290	1.317	1.339	1.333	**1.324**	1.36	1.25	1.28	1.35	1.32	**1.31**
P_3	0.73	0.59	0.62	0.69	0.68	**0.67**	1.310	1.231	1.309	1.324	1.215	**1.278**	1.27	1.11	1.15	1.21	1.18	**1.18**
P_4	0.54	0.41	0.46	0.50	0.48	**0.48**	1.285	1.150	1.211	1.215	1.203	**1.212**	1.11	1.01	1.04	1.08	1.06	**1.06**
P_5	0.47	0.33	0.35	0.41	0.38	**0.39**	1.131	0.956	0.978	0.982	0.988	**1.007**	1.09	0.90	0.93	0.97	0.95	**0.97**
P_6	0.38	0.20	0.26	0.32	0.27	**0.29**	0.985	0.879	0.934	0.947	0.932	**0.935**	0.98	0.79	0.86	0.89	.0.87	**0.88**
Mean	**0.72**	**0.56**	**0.60**	**0.64**	**0.62**		**1.253**	**1.170**	**1.207**	**1.220**	**1.196**		**1.29**	**1.16**	**1.20**	**1.24**	**1.22**	
	P		**M**		**PXM**		**P**		**M**		**PXM**		**P**		**M**		**PXM**	
SED	0.005		0.004		0.011		0.011		0.009		0.024		0.012		0.010		0.026	
CD(0.05)	0.010		0.009		0.023		0.022		0.018		0.487		0.023		0.020		0.053	

3. RESULTS

The results of this experiment revealed that the modified atmospheric storage condition, period of storage and their interactions showed significant effect with all the seed quality attributes.

Among the storage conditions, the maximum seed moisture content was recorded in kernel stored in gunny bags under ambient storage (M_2) while, the minimum was observed in nitrogen and vacuum storage (M_4&M_5). The moisture content was slowly increased from 6.3 to 7.4 %) as the advancement of storage period from P_0 to P_6. On the contrary, the highest germination percentage of 94 per cent at initial period of storage (P_0) was slowly decreased to 47 per cent at the end of the storage period (P_6). With respect to modified storage conditions,pod stored in gunny bag under ambient condition (M_1) recorded the maximum mean germination (73 %) and it was followed by kernel storage under nitrogen storage (M_4) (70 %) while, kernel storage at ambient condition (M_2) recorded the minimum mean germination percent (66 per cent)

Comment [S12]: match the others using symbols

Comment [S13]: match the others using symbols

The maximum root and shoot length of 14.6 and 14.3 cm were observed in pod stored in gunny bag under ambient storage (M_1) while, the minimum length of 13.6 and 13.0 cm were observed in kernel stored in gunny bag (M_2), respectively.The decline trend in seedling length was observed as the advancement of storage period**.** The similar trend was observed in dry matter production and vigour index **(Table. 1 &2).**

On the six month of storage period, there is no storage pest incidence was observed up to four months of storage (P_4) and then it was slowly increased to 0.4 (P_5) to 8 per cent (P_6). Similarly, the minimum pest incidence and fungus infection of 0.6 and 17 per cent were observed in pod stored in gunny bag while, they were maximum in kernel stored in gunny bag (1.1 and 27 %), respectively **(Table 3.).**

The enzymes *viz*., alpha amylase, dehydrogenase, catalase and peroxidase also have positive correlation with seed quality and initially they were maximum of 14.01 mg maltose min^{-1}, 1.00 OD value, 1.363 µmolH_2O_2 $min^{-1}g^{-1}$ protein and 1.63 U mg^{-1} protein min^{-1}while, it was minimum of 12.84 mg maltose min^{-1}, 0.29 OD value, 0.935µmolH_2O_2 $min^{-1}g^{-1}$ protein and 0.88U mg^{-1} protein min^{-1}, respectively. Similarly, the maximum enzyme activity was observed in pod stored in gunny bag and nitrogen storage, which was followed by vacuum storage **(Table 4)**.

4. DISCUSSION

Seed deterioration orageing is a universal physiological phenomenon which leads to loss of viability. The rate of seed deterioration is vary with the crop species and it is triggered by unfavourable storage conditions (Harrington, 1960 and Agrawal, 1980). Obviously, the seed deterioration rate is faster in oilseed crops and which is due to auto oxidation fatty acids i.e. more lipid peroxidation. In order to overcome or manipulate the deleterious effect of storage environment, MAS is a novel approach for storing groundnut kernels for longer period.

In the present study, it was evidenced that seed stored as such as a pod in gunny bag recorded good storability in terms of germination **(Plate 1)**, seedling length, dry matter production, vigour index and enzyme activities and it was equally on par with the kernel stored under

nitrogen storage. It clearly indicated that kernel storage also possible to maintain the storability in groundnut when kernels are stored under nitrogen which is followed by vacuum storage.

Comment [S14]:
it is best to complete supporting theories

The reason for the long term maintenance of seed quality in pod storage is due to the microclimate that prevails inside the pod. When the groundnut stored as pod it occupy more space than stored as kernel. The problem associated with kernel is auto-oxidation, peroxidation more prone to insect attack loss of natural antioxidant and rancidity which will affect the seeds standard and also make it unfit for human consumption. The seeds are naturally provided with both enzymatic and non enzymatic antioxidant which will protect the seeds under the adverse situation of lipid peroxidation. The seed coat with deeper color contain more polyphenol content and high flavonoid content and thus have the stronger antioxidant ability (Kuang *et al*. 2017).Vakeswaran*et al.,* (2017) suggested that the seeds stored with pod in the modified atmospheric packaging of 40% CO_2 given higher vigour and viability even after the 12 month of storage. Copeland (1985) highlighted the consequences of deteriorative changes in seed which include membranedegradation, accumulation of toxic metabolites, decreased enzymatic activity, lipid auto-oxidation, and failure of repair mechanisms, genetic degradation, and reduced yield, finally loss of germination or death. In kernel storage, the kernels are exposed to environment and this environment oxygen promote the auto-oxidation and lipid peroxidation in groundnut which results in the production free radical, hydrogen peroxide which damage cell structure and ultimately leads to poor seed viability.The similar result were also reported by Guillaumin (1928), Rathi *et al.*, (2000), Bera *et al*., (2004), and Bera *et al*., (2008).

Plate	Kernel stored in gunny bag	Pod stored in gunny bag	Kernel stored in nitrogen gas

1.

Comparative assessment seed and seedling quality of groundnut under modified atmospheric storage

Comment [S15]: Complete the description of what type of image the table is

5. CONCLUSION

Of the outset, it is concluded that groundnut kernels stored under modified atmospheric storage i.e., nitrogen gas storage can maintain the seed longevity by minimizing the deterioration process in groundnut equally as that of pod storage. Further, it will helps to minimize the expenditure towards transport and storage.

Comment [S16]: lengkapi dengan data dari hasil

REFERENCES

Abdul-Baki, A. A., & Anderson, J. D. (1973). Vigor determination in soybean seed by multiple criteria 1. *Crop science*, *13*(6), 630-633.

Agrawal,R.L. 1980. Seed technology. Oxford and IBH Publishing Co., New Delhi, India.

Bera A, Sinha SN, Ashok Gaur, Srivastava C.2008. Effect of carbon dioxide rich atmosphere on seed quality parameters of paddy. Seed Research; 36(1):56-63. 9.

Bera A, Sinha SN, Singhal NC, Pal RK, Srivastava C.2004 Studies on carbon dioxide as wheat seed protectant against storage insects and its effect on seed quality stored under ambient conditions. Seed Science and Technology; 32:159-169.

Copeland, L.L. (1985) Seed germination. In: Principles of Seed Sci. Technol., Surjeet Publications, Delhi; c1985. p. 55- 212.

FAOSTAT 2021. World Food and Agriculture - Statistical Yearbook 2021. Rome. https://doi.org/10.4060/cb4477en

Guillaumin, A. (1928). Le Maintien Des Graines Dans Un Milieu Prive D'oxygeneCommemoyen De Prolonger LeurFaculte Germinative. [Paris]. Acad. Des. Sci. Compt. Rend. 187: 571-572.

Harrington, J.F. Thumb rules of drying seed. *Crops Soils* **1960**, *13*, 16–17. [**Google Scholar**]

ISTA (2013) International Rules For seed testing Switzerland:International Seed Tesring Association

Kuang, Q., Yu, Y., Attree, R., & Xu, B. (2017). A comparative study on anthocyanin, saponin, and oil profiles of black and red seed coat peanut (Arachis hypogacea) grown in China. *International journal of food properties*, *20*(sup1), S131-S140.

Murali T. Variath and P. Janila. 2017. Economic and Academic Importance of Peanut. **In:** The Peanut Genome, Compendium of Plant Genomes, (Eds) R.K. Varshney *et al. 2017.* Springer International Publishing AG 2017, DOI 10.1007/978-3-319-63935-2_2

Panse, V.G. and Sukhatme, P.V. (1985) Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication, 87-89.

Rathi, S.S., Shah, N.G., Zambre, S.S., Kalbande, V.H. and Venkatesh, K.V. (2000). Respiration, sorption and germination of seeds stored in controlled atmosphere. Seed Science and Technology. 28: 341-348

Riudavets, J., Pons, M. J., Messeguer, J., &Gabarra, R. (2018). Effect of CO2 modified atmosphere packaging on aflatoxin production in maize infested with Sitophilus zeamais. *Journal of stored products research*, *77*, 89-91.

Vakeswaran, V. (2017). Assessment of the Pattern of Loss of Viability and Vigour of Ground Nut Seeds Stored as Pod and Kernel in Ambient and Modified Atmospheric Storage. *International Journal of Agriculture Sciences, ISSN*, 0975-3710.

Bonku, R., & Yu, J. (2020). Health aspects of peanuts as an outcome of its chemical composition. *Food Science and Human Wellness*, *9*(1), 21-30.

ISTA (2010) International Rules For seed testing Switzerland:International Seed Tesring Association

Paul, J. (1970). Cell and tissue culture. *Cell and tissue culture.* (4th Edition).

Aebi, H. (1984). Catalase in vitro. In *Methods in enzymology* (Vol. 105, pp. 121-126). Academic press.

Malik, R. K., & Singh, C. (1980). The effect of organic acids and cycocel on peroxidase activity of cotton seedlings. *Agrochimica*, *24*(5/6), 478-481.

Kittock, D. L., & Law, A. G. (1968). Relationship of seedling vigor to respiration and tetrazolium chloride reduction by germinating wheat seeds 1. *Agronomy Journal*, *60*(3), 286-288.